GILA RIVER STREAMFLOW RECONSTRUCTION

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PREFACE

The Laboratory of Tree-Ring Research was contacted by the U.S. Bureau of Land Management (BLM) in the fall of 1991 to investigate the potential of extending streamflow records on the Gila River using tree-ring data. A dendrohydrology study of the upper Gila River was initiated in March, 1992, as BLM Project No. 1422A040C20001, "Gila River Streamflow Reconstruction". The Principal Investigator on the project was David Meko. The study used tree-ring chronologies previously developed by Donald A. Graybill.

We thank Mike McQueen, of the Safford Office of the BLM, for initiating the project and providing guidance and suggestions throughout the course of the work, and Gary Funkhouser and Wanmei Ni for their help in computer processing of data.

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EXECUTIVE SUMMARY

Streamflow in the upper Gila River Basin is strongly influenced by climate variations at time scales of decades and longer. The climate influence in the 20th century is clearly demonstrated by large fluctuations in streamflow averaged over several years, and by multi-decadal trends in streamflow. For the Gila River at the head of Safford Valley, Arizona, a distinct climate signature in the streamflow record is a shift from high flow in the 1910s to low flow in the 1950s, and again to high flow in the 1980s. Imbedded within the large changes in annual streamflow are changes in flood frequency. Large peak annual flows on the Gila River were much more common after 1973 than in the period 1918-1972.

A critical question for water-resource management is whether the gaged record is a representative sample of natural variations in annual streamflow and peak flow. This question can be answered by extending the gaged record statistically using tree-ring analysis. A tree-ring study was commissioned with the following objectives:

1. Reconstruct annual flow series for the Gila and San Francisco Rivers for the last 300 to 700 years.
2. Establish the return periods for extremely low annual streamflow.
3. Provide an analysis of the variability of historic mean annual streamflow.
4. Analyze the gaged and reconstructed streamflow record for decadal and multi-decadal trends in mean annual flow.
5. Provide an analysis of return periods for peak streamflow events for the period of gaged record, and extend this analysis with tree rings, if feasible, to cover earlier periods.

A network of nine tree-ring chronologies, each comprising 10 or more trees, was developed for the study. The tree-ring data were applied in regression models to derive statistical estimates of log-transformed annual flow for the period 1663-1985. Reconstructions of annual flow (1663-1985) were generated for three gages: the Gila River at the head of Safford Valley, the Gila River near Clifton, and the San Francisco River at Clifton. The regression equations explain more than 60 percent of streamflow variance in the 1916-1985 calibration period. The reconstruction was found to closely track observed calibration-period flow variations at interannual to multi-decadal time scales.

The reconstruction for the gage on the Gila River at the head of Safford Valley was analyzed statistically for a long-term (323-year) perspective on flow variations. Findings of the study are summarized below:

1. Low flows are more frequent in the modern period (1916-1985) than in the long-term period (1663-1985). The difference in frequencies results largely from a period of recurrent low-flow years in the 1950s. The probability of annual flow less than a specified value over the range 80,000 acre-ft to 150,000 acre-ft is greater in the modern period than for the long-term period. The modern period does not, however, include the minimum reconstructed annual flow. The long-term minimum annual flow (49,055 acre-ft) is considerably lower than the modern minimum (73,050 acre-ft observed, 74,399 acre-ft reconstructed).

2. The reconstruction indicates that mean annual streamflow computed for a 70-year base period is highly variable. Reconstructed 70-year means vary by more than 100,000 acre-ft. The extremes are 378,890 acre-ft for 1865-1934 and 269,627 acre-ft for 1713-1782. The modern reconstructed mean is slightly lower than the long-term reconstructed mean, but is extremely sensitive to shifting the averaging period by a just a few years.

3. Trends and large multi-decadal fluctuations in annual flow are characteristic of the long-term record, but have increased in magnitude since about 1905. A cluster of high-flow years in the early 1900s and a cluster of low flow years in the 1950s impart a downward trend to smoothed time series of annual flow. This trend is more prominent than any trend before the 20th century. The clusters of high-flow and low-flow years produce the long-term extremes in 10-year average flow. The lowest reconstructed ten-year mean (171,596 acre-ft) was for 1947-1956. This value was about 25,000 acre-ft

lower than the next lowest mean, which occurred in the 1600s. The highest ten-year mean (788,043 acre-ft) was for 1906-1915. This value more than 300,000 acre-ft higher than the second-highest ten-year mean, which occurred in the late 1700s.

5. The 100-year flood for the Gila River at the head of Safford Valley was computed from gaged data, 1914-1988, as 88,500 cfs. Peak annual flow is significantly correlated with total annual flow. The relationship between peak flow and ring-width indices of drought-sensitive trees is too weak, however, for accurate reconstruction of flood history before the period of gaged flow.

6. The accuracy of annual flow reconstructions presented here is moderately high compared with accuracy for similar reconstructions in other basins in the western United States. Accuracy possibly could be improved by expanding the tree-ring coverage in the watershed. Alternative information on flood frequency might be available using paleoclimate methods beyond the scope of the current study -- for example, examination of accurately dated flood scars in riparian trees.

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1. INTRODUCTION

Streamflow records in areas of the United States with widely varying hydrologic and climatic regimes have been successfully reconstructed from tree rings (e.g., Stockton and Jacoby 1976; Smith and Stockton 1981; Cook and Jacoby 1983; Earle and Fritts 1986; Cleaveland and Stahle 1989). Such reconstructions have been most useful for their information on flow variability at time scales of decades to centuries -- variability difficult or impossible to study with short gaged records. Tree-rings in the southwestern United States have long been recognized as excellent proxy series for moisture variations (Schulman 1956). As a result of field collections in the 1980s, a network of tree-ring sites with reasonably dense spatial coverage now exists to study the pre-gage flow history of the upper Gila River in western Arizona and eastern New Mexico.

This report describes results of a hydrologic and tree-ring analysis of streamflow of the upper Gila River. Annual flow is reconstructed to A.D. 1663 for three gages in the Gila River basin:

4485 Gila R. at head of Safford Valley, near Solomon, AZ
4420 Gila R. near Clifton, AZ
4445 San Francisco R. at Clifton, AZ

The text focuses on results for gage 4485. Both the gaged and reconstructed record for gage 4485 are analyzed for trends, decadal-scale variations, and recurrence intervals of low flow. The relationship between annual peak flows and annual total flows for gage 4485 is also analyzed to explore the possibility of inferring past flood peaks from the tree-ring records. Reconstructions for gages 4420 and 4445 are not discussed in detail in the text, but are included in appendixes.

2. STUDY AREA

The watershed of the Gila River above gage 4485 at the head of Safford Valley, Arizona, encompasses 7,896 mi^2 in southeastern Arizona and southwestern New Mexico (Figure 1). Surface-water resources of the Gila Basin are described by Anderson and White (1986) and Gold and Denis (1986). Runoff for the Gila River comes primarily from precipitation in the highlands of eastern Arizona and western New Mexico. The watershed of the Gila River upstream of Coolidge Dam is mainly mountains and grassland. Annual precipitation ranges from less than

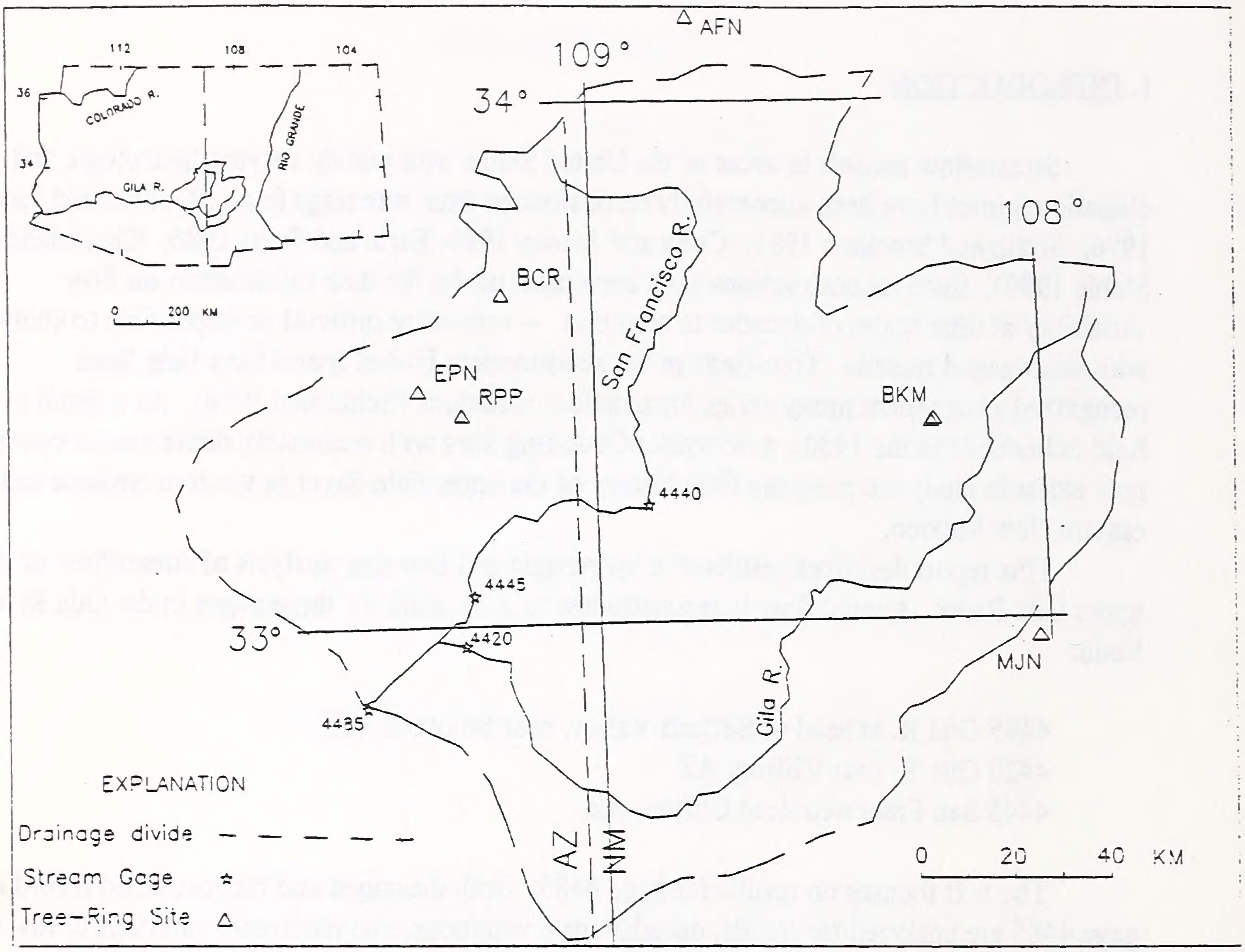

Figure 1. Map showing boundary of basin and locations of streamflow gages and tree-ring sites.

10 inches along the river bottom to more than 40 inches in the higher mountains (Burkham 1970). Annual runoff ranges from less than 0.2 inches in the valleys to more than 2 inches in the higher mountains. Annual precipitation is bimodal, with a summer primary maximum and a winter secondary maximum (Anderson and White 1986; Gold and Denis 1986).

Gage 4485 measures outflow from the study area. Gages 4445 and 4420 measure components of flow from the San Franciso River and the Gila River above its confluence with the San Francisco River. The San Francisco River drains the northern and western parts of the study area; the Gila River above gage 4420 drains the eastern and southern parts. Drainage areas and discharges for the three gages to be reconstructed, and for gage 4420 -- the San Francisco River near Glenwood, New Mexico -- are listed in Table 1. The sub-basins represented by gages 4445 and 4420 contribute nearly equal mean annual flows to the Gila River. The record for gage 4440 is used in this report only for filling in missing monthly flow values at other gages.

3. DATA

Monthly flow data for gages 4485, 4445, 4420 and 4440, and a peak annual flow series for gage 4485 were obtained from EarthInfo, Inc.'s (1990) compact-disk version of the U.S. Geological Survey database. Periods of record for the monthly-total series at the various gages are listed in Table 1. Data are available for as early as October, 1910, at gage 4445, but records for that gage and gage 4420 do not become reasonably continuous until water year (WY) 1928 (U.S. Geological Survey 1970). Gage 4485 has the longest reasonably continuous record, extending back to WY 1915 with only a few missing monthly values.

Monthly flow series for all gages were converted to unbroken series over WY 1911-1990 by filling in missing values using the U.S. Army Corps of Engineers (1971) HEC-4 Monthly Streamflow Simulation computer program. Details of the estimation procedure are deferred to Appendix 6. The full set of original (raw) and estimated monthly data is included as Appendix 1.

Accuracy of discharge records is graded by the U.S. Geological Survey as "good" or "fair", if 95 percent of the daily discharge measurements are within 10 percent or 15 percent, respectively, of the true discharge. Quality for gages 4485 and 4445 is good, and for gage 4420 is fair (U.S. Geological Survey 1970).

The degree to which gaged flow data represent natural (unaffected by man) conditions is critical to use of the data in tree-ring reconstructions. The Gila River above gage 4485 is unregulated by major reservoirs (Anderson and White 1986; U.S. Geological Survey 1970). Of the three gages reconstructed in this report, 4445 is probably the least distorted by man's activities. Records are affected to varying degrees by upstream diversions, mainly for irrigation. As of 1970, water was diverted for irrigation of the following acreage upstream of the three gages:

Table 1. Gages used in the study

GAGE NUMBER AND NAME		PERIOD[a]	AREA (Sq mi)	AVERAGE DISCHARGE[b] (Acre-ft)
4485	Gila R. at head of Safford Valley	1914-1990	7,896	315,180
4420	Gila R. near Clifton, AZ	1910-1990	4,010	128,630
4445	San Francisco R. at Clifton, AZ	1910-1990	2,766	145,140
4440	San Francisco R. near Glenwood, NM	1927-1990	1,653	61,450

[a] Includes intervals of missing data
[b] Computed over common period 1929-1989 for all gages

Gila R. near Clifton	14,300 acres
San Francisco R. at Clifton	2,700 acres
Gila R. at head of Safford Valley	17,500 acres

Annual discharge records were not adjusted in this study for changes in diversions over time. Increased noise in the statistical relationship between discharge and tree-ring data is the likely result of such changes. The severity of the problem depends on how badly the annual flow record is distorted. As an example of a worst-case scenario for the San Francisco River, assume that the total irrigation consumptive use is superposed as a distortion on the annual flow. A crop water requirement of 3 feet per year is reasonable for several crops grown in eastern Arizona and western New Mexico (p. 36, Doorenbos and Pruitt 1977). Reduction of the diversions on the San Francisco R. to zero would add 2,700 X 3 = 8,100 acre-ft to the annual discharge. The equivalent percentage change in annual discharge is about 6%. The percentage change for the same scenario would be considerably larger for the other two gages. Although the amount of irrigated acreage in the study area suggests a potential for distortion of the gaged flows, comparison of flow records at gage 4485 with precipitation records in the basin suggests otherwise: the ratio of streamflow at gage 4485 to precipitation averaged over several station was found by Burkham (1970) to be stable from the beginning of record to the 1960s.

Tree-ring data consist of a set of nine ringwidth chronologies from six separate sites. These data were collected and developed by one of the authors (DAG). Site locations are shown in Figure 1, and species identification and other information on the chronologies are listed in Table 2. Chronologies from four different species at Black Mountain, New Mexico, were combined into a single Black Mountain (BKM) chronology for purposes of this study.

The six tree-ring sites sample both sub-basins of the study area. Sites MJN and BKM are in or near the Gila River watershed above gage 4420; the other four sites are in or near the watershed of the San Francisco River. Sites AFN and MJN are a few kilometers outside the watershed boundaries.

Tree-ring data had previously been crossdated, measured and standardized into indices of annual growth following conventional procedures (Fritts 1976). All data are fairly recent collections, with ending dates of 1986 or later. The period of coverage by all chronologies extends back to A.D. 1663. The raw tree-ring data for calibration with streamflow in regression models are autoregressive-residual chronologies from program INDEX (Graybill 1979a; Graybill 1979b; Graybill 1982). Annual time series for the six residual chronologies for the common period 1662-1986 are listed in Appendix 3.

Table 2. Site information for tree-ring chronologies.

SITE	CODE[a]	SPEC[b]	LAT.	LONG.	ELEV. (ft)
AGUA FRIA, NM	AFN	pe	34°15'	108°37'	7300
BEAVER CREEK, AZ	BCR	pp	33°42'	109°14'	7850
BLACK MOUNTAIN, NM	BKM	pp,df,wp,wf	33°23'	108°14'	8400-9300
EAGLE CREEK, AZ	EPN	pe	33°28'	109°29'	5560
MIMBRES JUNCTION, NM	MJN	pe	32°57'	108°01'	6400
ROSE PEAK, AZ	RPP	pp	33°25'	109°22'	7600

[a] also used as map reference (Figure 1)

[b] species coded as follows:

pe = Pinyon pine (Pinus edulis)
pp = Ponderosa pine (Pinus ponderosa)
df = Douglas-fir (Pseudotsuga menziesii)
wp = White pine (Pinus strobiformis)
wf = White fir (Abies concolor)

4. METHODS

Conventional methods for hydrologic and tree-ring analysis were followed. An overview of methods used is given in this section. Details are discussed more fully when required in the "results" section.

Univariate and bivariate distributions of data were studied with box plots and scatter plots. The box plot (described later) is a simple alternative to the histogram. Reconstruction models were derived by multiple linear regression (Draper and Smith 1981). The predictand variable was first log-transformed so that assumptions of the model were satisfied. Reconstruction models were indirectly verified by a split-sample scheme -- first calibrating on half the data and verifying on the other half, and then exchanging the periods used for calibration and verification. The final reconstruction model was calibrated using the full period of available data.

Calibration and verification accuracy was measured by a suite of commonly used statistics. Strength of the calibration was measured by the squared multiple coefficient of determination, R^2. Verification accuracy was measured by comparing model (reconstructed) and observed flows outside the calibration period by: correlation coefficients, tests of difference in means, sign tests, and the reduction of error (RE) statistic. All except the RE statistic are described in general statistics or regression textbooks (e.g., Draper and Smith 1981). The RE statistic as applied to tree-ring reconstructions is described by Fritts (1976).

Time series were smoothed by moving averages and cubic smoothing splines. The moving average is straightforward and easily interpreted, but is sometimes misleading in location of peaks and troughs. The cubic smoothing spline (de Boor 1978) avoids this problem, and allows great flexibility in following low frequency variations with control over the frequency response (Cook and Peters 1981).

The method for filling in missing monthly streamflow values has been mentioned previously, and is described in more detail in Appendix 6.

The flood-frequency analysis was done using the classical approach recommended by the Water Resources Council (1981). Details are described later in this report.

5. RESULTS

5.1 Calibration-Verification of Reconstruction Models

Data Transformation. Application of linear regression models to the streamflow-tree ring relationship assumes first that the relationship is linear. If so, the shapes of the univariate frequency distributions of the two types of data should be similar. Box plot summaries for WY flow at gages 4485, 4445 and 4420, and for tree-ring indices at three sites in the study area show that the distributions of flow and tree-ring data are in fact radically different (Figure 2). Gaged flow is much more highly skewed (positive skew) than tree-ring series. The tree-ring series plotted are much more symmetrically distributed, and tend toward a negative skew. A simple linear regression of WY flow against a tree-ring series for these data would necessarily give a reconstructed flow with the same shape of frequency distribution as the tree-ring series -- a radical inconsistency with the distribution of observed streamflow.

Bivariate scatter plots for WY flow at gage 4485 (WY4485), the log-10 transform of WY4485, and tree-ring chronologies from three sites also suggest a problem with regression of untransformed flow against tree rings (Figure 3). Plots in columns 3-5, row 1 of Figure 3 show a highly nonlinear and heteroscedastic relationship between the original flow series and tree rings. Plots in columns 3-5, row 2, show the effect of log-transforming the flow series. The relationship after transformation appears to be approximately linear. The relationship between log-flow and tree rings is also highly significant (p-value < 0.00001) based on a two-tailed test of the Pearson correlation coefficient. The relationship between log-flow and tree-ring series is about as strong as the relationship between tree-ring series.

The observed relationships suggest log transformation of flow before use in regression modeling. Log transformation has been previously used in tree-ring reconstructions of river flow by Smith and Stockton (1981) and Cook and Jacoby (1983). Other flow-reconstruction studies have dealt with less extreme distribution problems that did not require transformation (e.g., Stockton and Jacoby 1976; Cleaveland and Stahle 1989).

Model Building and Parameter Estimation. The predictand for a regression equation was log-10 WY gaged flow. Separate regression models were estimated for gages 4485, 4445 and 4420. Predictor variables were allowed to enter stepwise (Draper and Smith 1981) until the adjusted coefficient of multiple determination (R^2) began to drop. As a safeguard against overfitting, the change of verification statistics with model growth was examined with a data-splitting verification procedure.

Tree-rings from 6 sites, lagged -1, 0, and +1 years from the water year of the streamflow series, were the potential predictors in the models. Negative-lagged predictors were allowed in the model because the method of prewhitening tree-ring indices with univariate ARMA models cannot be assumed to optimally account for or remove persistence related to a bivariate (climate-

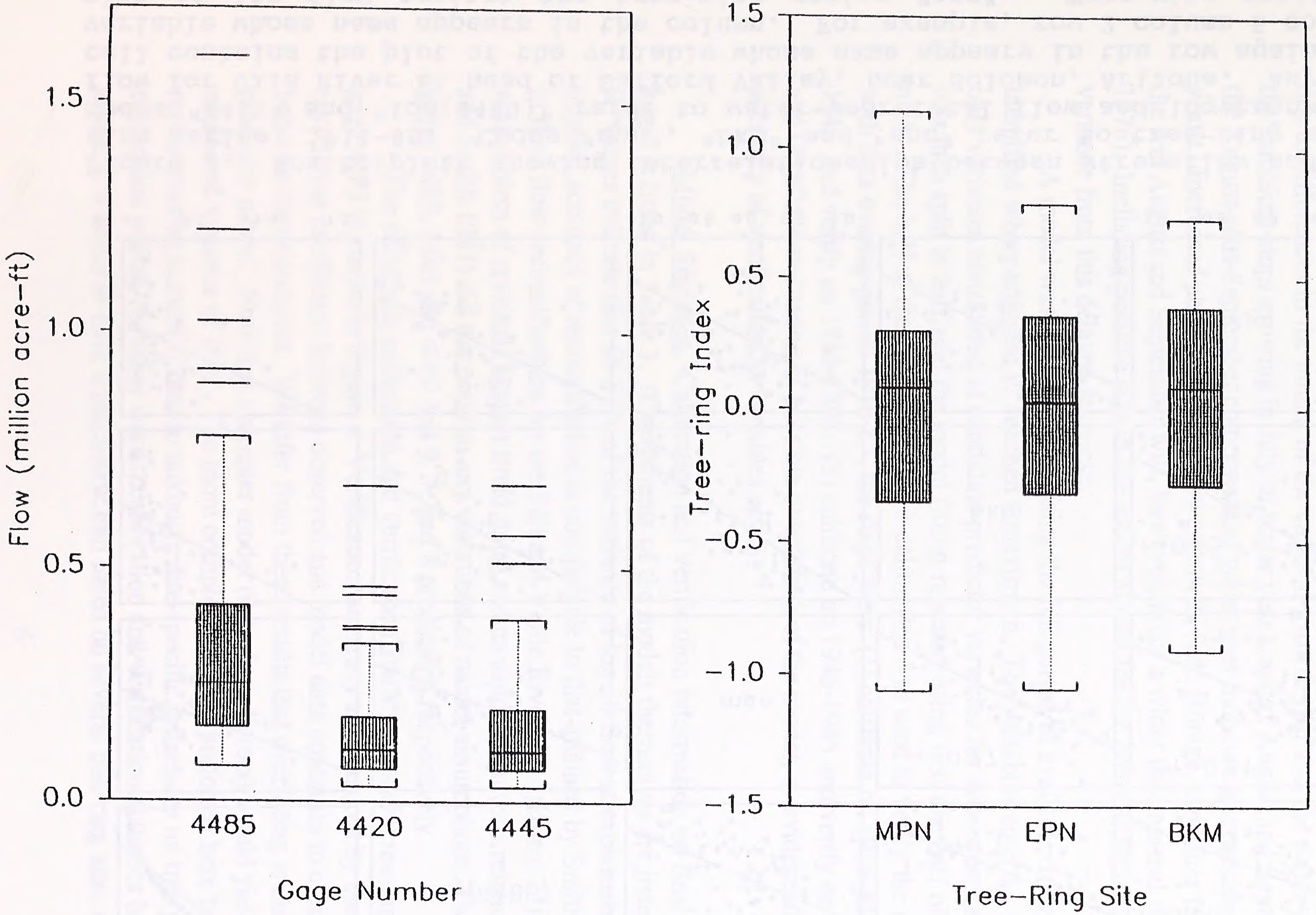

Figure 2. Boxplots comparing frequency distributions of streamflow and tree-ring series. Box encloses 25th to 75th quantile of data. Horizontal line in box marks median. Brackets extend to either 1.5 times the interquartile distance (third minus first quartile) from the median, or to the extremes of the data, whichever is less. For normally distributed data, 99.3% of the observations fall within the brackets. Isolated horizontal lines are outliers. See Table 2 for identification of tree-ring sites.

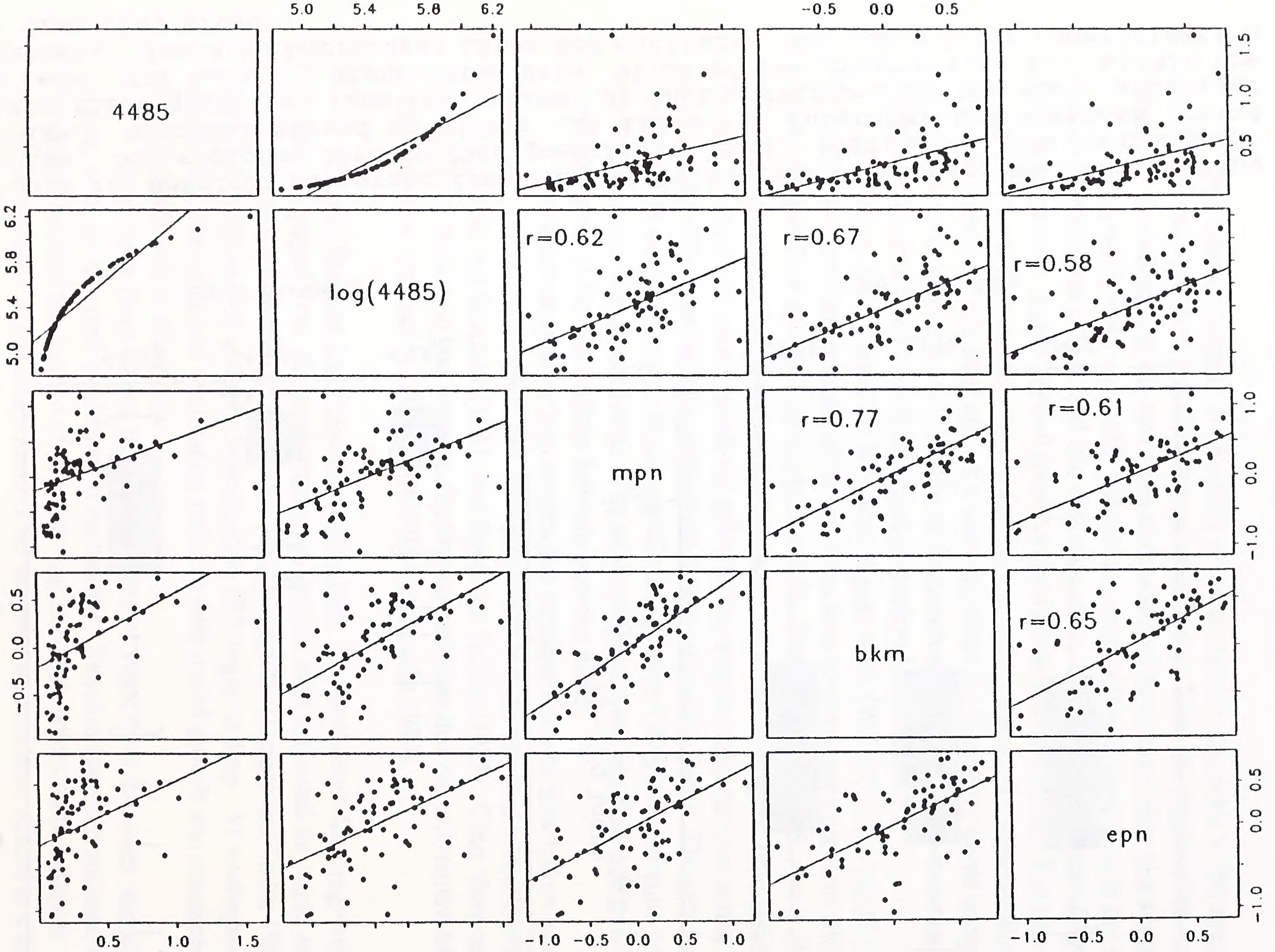

Figure 3. Scatterplots showing interrelationships between streamflow and tree-ring series, 1911-86. Codes "mpn", "bkm" and "epn" refer to tree-ring series. Codes "4485" and "log(4485)" refer to water-year-total flow and log-transformed flow for Gila River at head of Safford Valley, near Solomon, Arizona. Any given cell contains the plot of the variable whose name appears in the row against the variable whose name appears in the column. For example, row 2 column 5 contains plot of log flow against the tree-ring series "epn". Tree-ring series are autoregressive residual chronologies, in index units. Flow data are in million [illegible]e-f[illegible]r [illegible] of[illegible]re-ft.

tree ring) system. Conversion of tree-ring series to ARMA residuals is equivalent to high-pass filtering. Reduction of tree-ring series to white noise in ARMA modeling may remove climatically related persistence. Including negatively lagged predictors allows the high-pass filtering of ARMA modeling to be undone to a degree if the result is an increase in explained climate variance. Positively lagged predictors were allowed in the model to allow for adjustment due to differences in the timing of the cambial-growth year and the water year. For example, if the cambium stops growing in July of water year t, and if August and September are very wet, the August-plus-September component of water year moisture goes undetected in tree rings for year t. Increased photosynthesis, crown growth, food storage, and other factors associated with the wet August and September will, however, favor a wider than normal ring in year t+1 (Fritts 1976). Including positive lags in the model allows for the possible increase in explained variance from this delayed response.

A model was first estimated using the full period of available data, and the point was identified where adjusted R^2 reached a maximum. The variables entering in this model were the only variables considered as candidate predictor variables for subsequent analysis. The data set was then split in half, and the model fitting repeated using first one half of the data and then the other. The half of the data not used for calibration was used to verify the model. For gage 4485, with data overlap period 1916-85, the steps were: (1) calibrate on 1916-85, (2) calibrate on 1916-1945 and verify on 1946-1985, (3) calibrate on 1946-1985 and verify on 1916-1945. Steps (2) and (3) allow evaluation of possible overfitting of the model, as evidenced by decreasing accuracy of verification as variables enter.

Model Statistics. Calibration and verification information on final models for the three gages is listed in Table 3. (Coefficients of the models themselves are listed in Appendix 3.) The R^2 values indicate that 66-67% of the variance of log-10 flow is explainable for each gage. The implied accuracy of reconstruction is comparable to that attained by Smith and Stockton (1981) in their flow reconstructions for the Salt and Verde Rivers in Arizona. Histograms of residuals, scatter plots of residuals against fitted data, and measures of autocorrelation of residuals (Draper and Smith 1981) did not point to any violations of model assumptions. The final models for gages 4485, 4445 and 4420 had 9, 7, and 8 predictors, respectively.

The change in calibration and verification statistics with increasing model complexity for gage 4485 is shown in Figure 4. Verification accuracy as measured by the RE statistic and the correlation coefficient between observed and model data continues to climb as the model becomes more complex. We infer from these results that overfitting is not a problem with a 9-predictor model. Note that a simpler model (3 or 4 predictors) would yield only slightly less explained variance of flow. The more complex model is preferred here because the reconstruction is more robust to unknown site-specific influences on tree growth before the calibration period. In other words, calibration and verification statistics being approximately equal, it is better to have a reconstruction based on several tree-ring sites scattered over the basin

Table 3. Calibration and verification statistics for reconstruction models.

	Gage 4485	Gage 4420	Gage 4445
MODEL PERIODS			
FINAL CALIBRATION	1916-85	1930-85	1930-85
SPLIT-1			
Calibrate	1916-50	1930-57	1930-57
Verify	1951-85	1958-85	1958-85
SPLIT-2			
Calibrate	1951-85	1958-85	1958-85
Verify	1916-50	1930-57	1930-57
FINAL CALIBRATION			
R-Squared	0.66	0.67	0.66
R-Squared, Adjusted	0.61	0.62	0.62
SPLIT-1			
R-squared	0.66	0.81	0.72
R-squared, adjusted	0.53	0.72	0.62
r-squared	0.64	0.41	0.71
RE statistic	0.61	N/A	N/A
P-values			
Diff. of Means	0.587	0.102	0.003
Sign test-1	0.310	0.186	0.037
Sign test-2	0.432	0.092	0.081
SPLIT-2			
R-squared	0.70	0.69	0.69
R-squared, adjusted	0.59	0.56	0.58
r-squared	0.58	0.48	0.71
RE statistic	0.52	N/A	N/A
P-values			
Diff. of Means	0.996	0.552	0.778
Sign test-1	0.999	0.186	0.852
Sign test-2	0.883	0.509	0.732

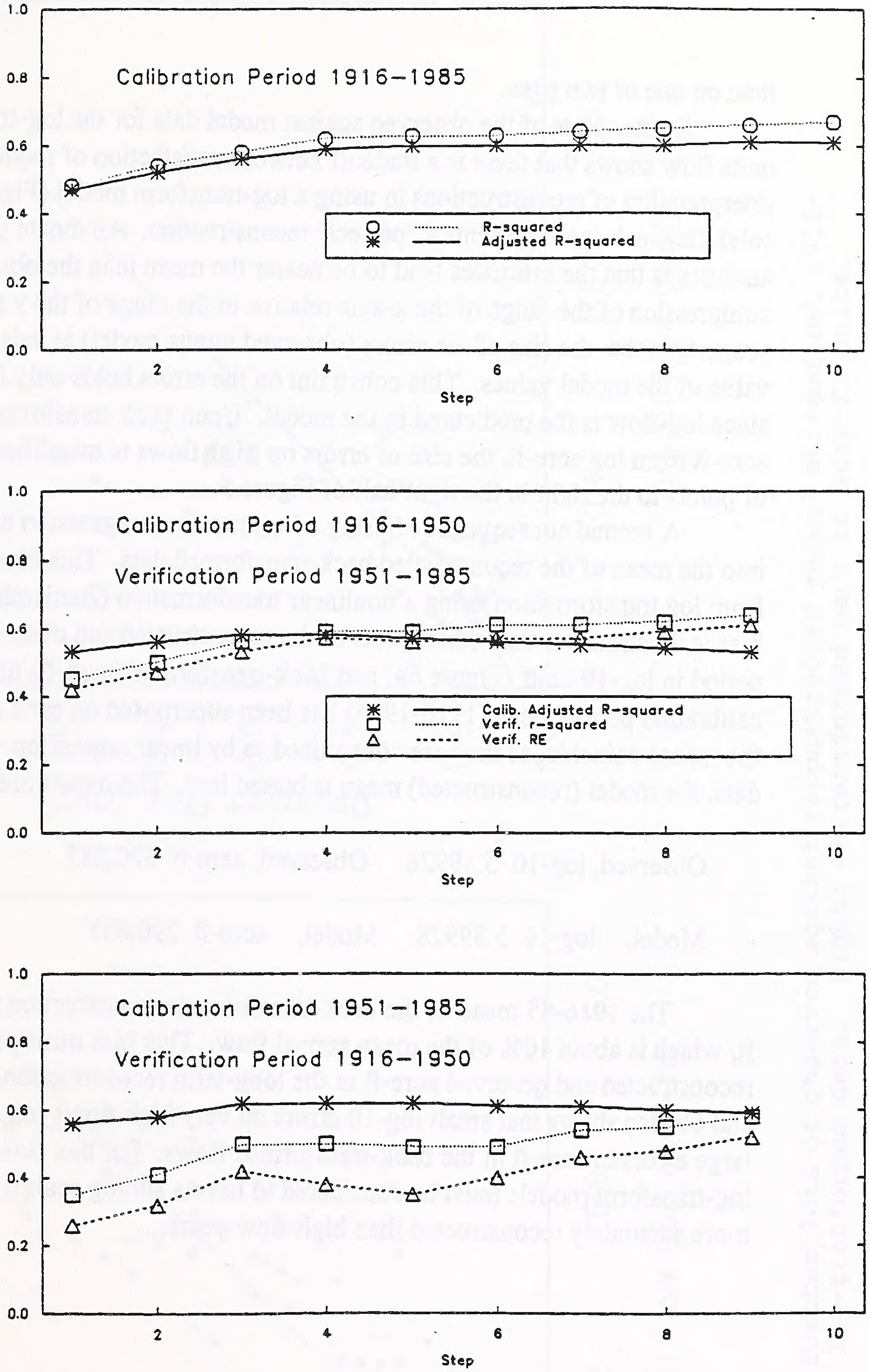

Figure 4. Graphs showing change in calibration and verification statistics with increasing number of predictors in model. Top: calibration-period. Middle: split period 1. Bottom: split period 2.

than on one or two sites.

Scatter plots of the observed against model data for the log-transformed and original-units flow shows that there is a tradeoff between satisfaction of model assumptions and ease of interpretation of reconstructions in using a log-transform model (Figure 5). In this figure, the solid diagonal line represents a "perfect" reconstruction. An innate property of regression analyses is that the estimates tend to be nearer the mean than the observed data are -- thus the compression of the range of the x-axis relative to the range of the y axis in Figure 5. Another property is that the size of the errors (observed minus model) is independent of the absolute value of the model values. This constraint on the errors holds only for the log-flow, however, since log-flow is the predictand in the model. Upon back-transforming the reconstruction to acre-ft from log acre-ft, the size of errors on **high** flows is magnified, as shown by the expansion of points to the right in the right half of Figure 5.

A second consequence of using a log-transform regression model is that a bias is built into the mean of the reconstructed back-transformed data. This bias is unavoidable, and results from log transformation being a nonlinear transformation (Benjamin and Cornell 1970). The bias is illustrated in time series plots of the reconstructed and observed data for the calibration period in log-10 units (Figure 6a) and back-transformed (acre-ft) units (Figure 6b). The calibration period mean (1916-1985) has been superposed on each figure. For the log-10 data, the means coincide, as they are constrained to by linear regression. For the back-transformed data, the model (reconstructed) mean is biased low. The means are:

Observed, log-10	5.39928	Observed, acre-ft	320,285
Model, log-10	5.39928	Model, acre-ft	290,635

The 1916-85 mean of the back-transformed reconstruction is biased low by 29,650 acre-ft, which is about 10% of the mean annual flow. This bias must be kept in mind in comparing reconstructed and observed acre-ft in the long-term reconstruction. A comparison of Figures 6a and 6b also shows that small log-10 errors on very high flows (e.g., WY 1979) translate into large errors in acre-ft in the back-transformed flows. For this reason, the reconstructions from log-transform models must be considered to have a sliding scale of accuracy: low-flow years more accurately reconstructed than high-flow years.

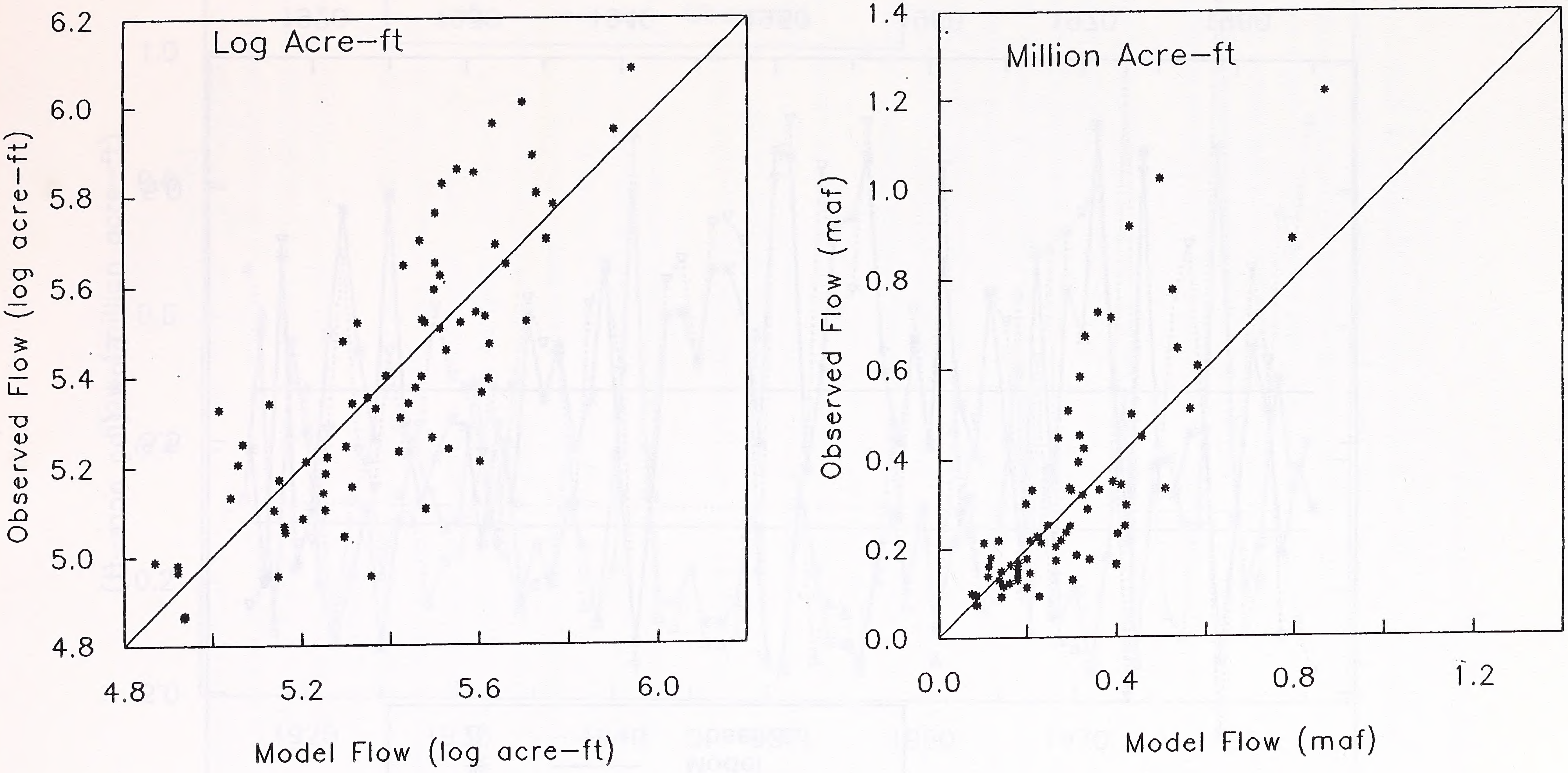

Figure 5. Scatterplots of observed against reconstructed annual streamflow, 1916-85. Left: log-tranformed data. Right: untransformed back to acre-ft units.

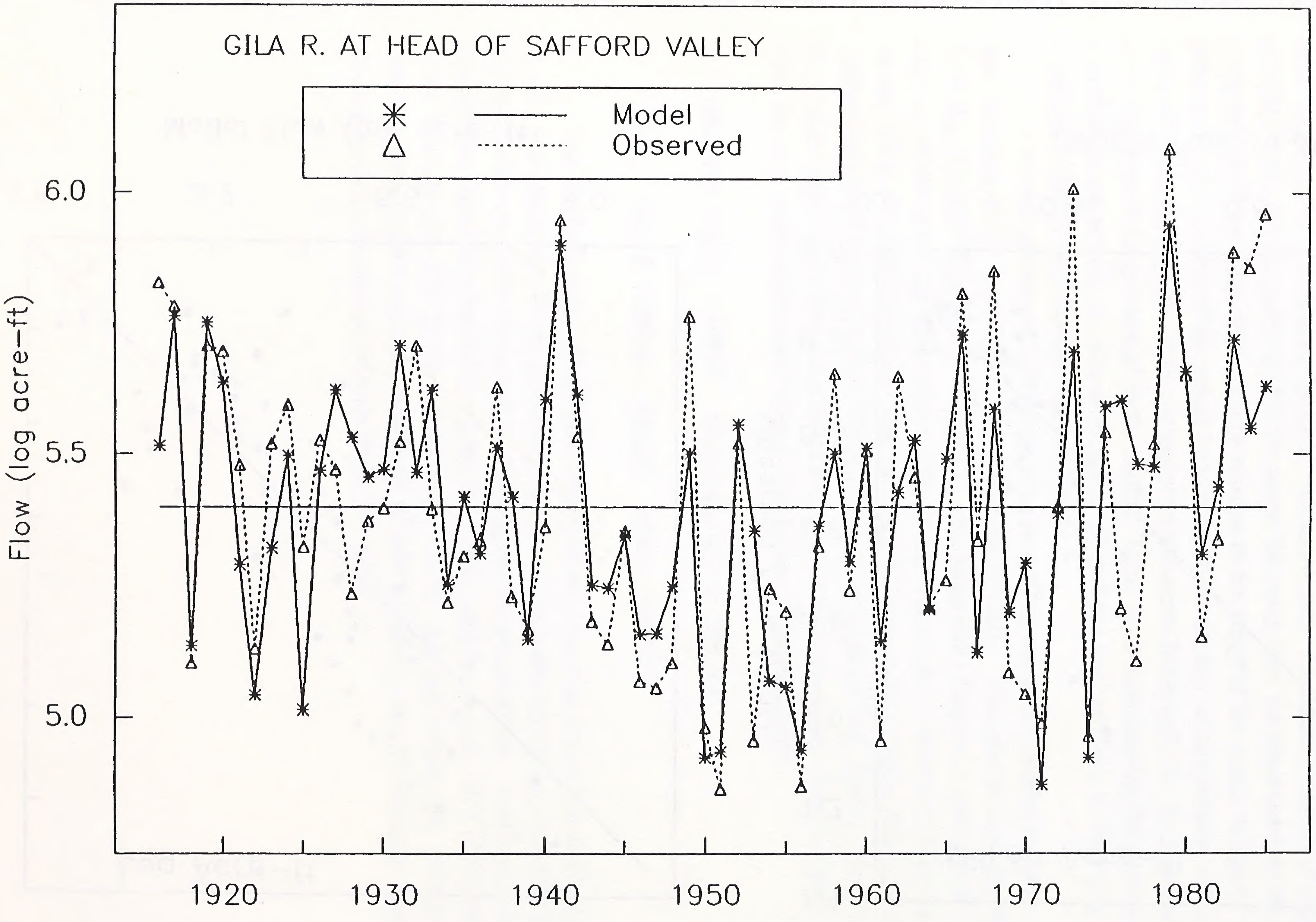

Figure 6a. Time series plots of observed and reconstructed log-10 annual flow for 1916-85 at gage 4485.

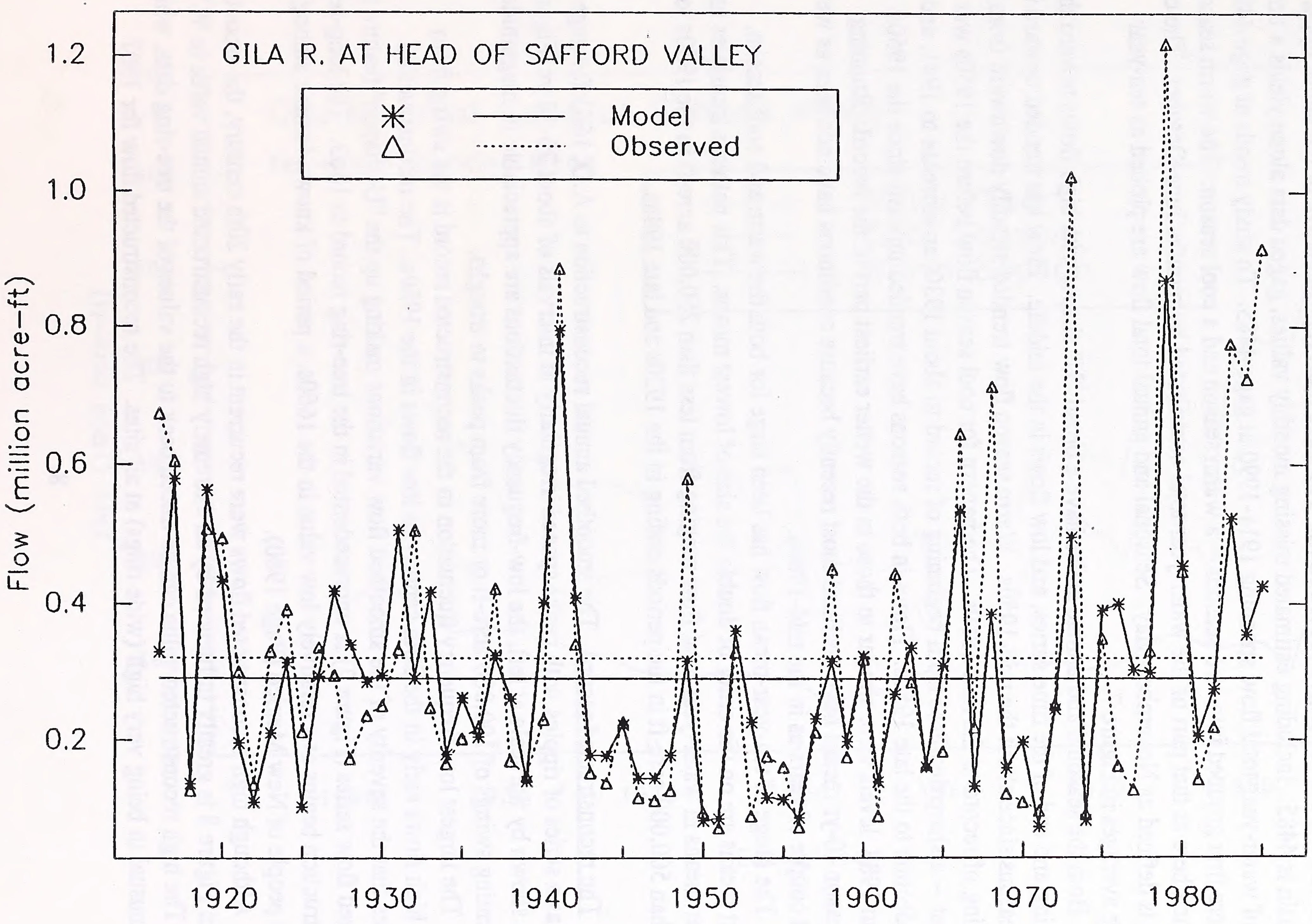

Figure 6b. Time series plots of observed and reconstructed annual flow for 1916-85 at gage 4485 in acre-ft. Offset in horizontal means shows bias in mean resulting from log-transform regression model.

5.2 Decadal and Multi-decadal Trends

The gaged record. The most reliable source of information on trends in streamflow over the modern period is the gaged record itself. The gage most representative of the entire upper Gila basin is 4485. Including estimated missing monthly values, gaged data alone yields a time series of water-year-total flow spanning 1911-1990 at gage 4485. To study trends at gage 4485, data were first grouped into two seasons -- a warm season and a cool season. The warm season is defined here as that part of the water-year total contributed by months June-October. The cool season is defined as November-May. Seasonal and annual total flow are plotted as ten-year moving averages in Figure 7.

Both the seasonal and annual series have a broad "U" shape, with high flows toward the beginning and end of the time series, and low flows in the middle. Flow has trended upward in both seasons since about the mid-1950s. Warm season flow trended steadily downward from the beginning of record to the mid-1950s. The pattern for cool season flow before the 1950s was different -- a sharp decrease from beginning of record to about 1930, an increase to 1941, and then a decline to the late 1950s. Flows in both seasons have trended upward since the 1950s. As of about 1988, levels were similar to those in the wetter earliest part of the record. Running cool-season 10-yr means have declined most recently because conditions have not been as wet in the last couple of years as in the mid-1980s.

The range of ten-year-mean flow has been large for both the warm and cool season. Highest means are on the order of double the size of lowest means. This patterns translates into ten-year means in water-year total flow ranging from less than 250,000 acre-ft in the 1950s to more than 500,000 acre-ft in the periods ending in the 1920s and late 1980s.

The reconstructed record. The smoothed annual reconstruction to A.D. 1663 for gage 4485 has a series of ripples with peaks spaced irregularly at intervals of about 20-50 yr (Figure 8). As shown by the scale at left, the low-frequency fluctuations are appreciable in magnitude, representing swings of 100,000 acre-ft or more from peaks to troughs.

The largest low-frequency fluctuation in the reconstructed record is the swing from record high flows early in the 20th century to low flows in the 1950s. The reconstruction indicates that the severity of the smoothed flow variations making up the "U-shaped" feature in the gaged flow series (Figure 7) is unprecedented in the tree-ring record to 1663. The long-term reconstruction begins at a relatively low value in the 1660s, a period of known famine among the Pueblo people of New Mexico (Page 1980).

Although high reconstructed flows were recurrent in the early 20th century, the smoothed series in Figure 8 is greatly influenced by an extremely high reconstructed annual value in WY 1907. The high reconstructed value can be traced back to the values of the tree-ring data, which were unusual in being very high (wide rings) at all sites. The reconstructed flow for 1907

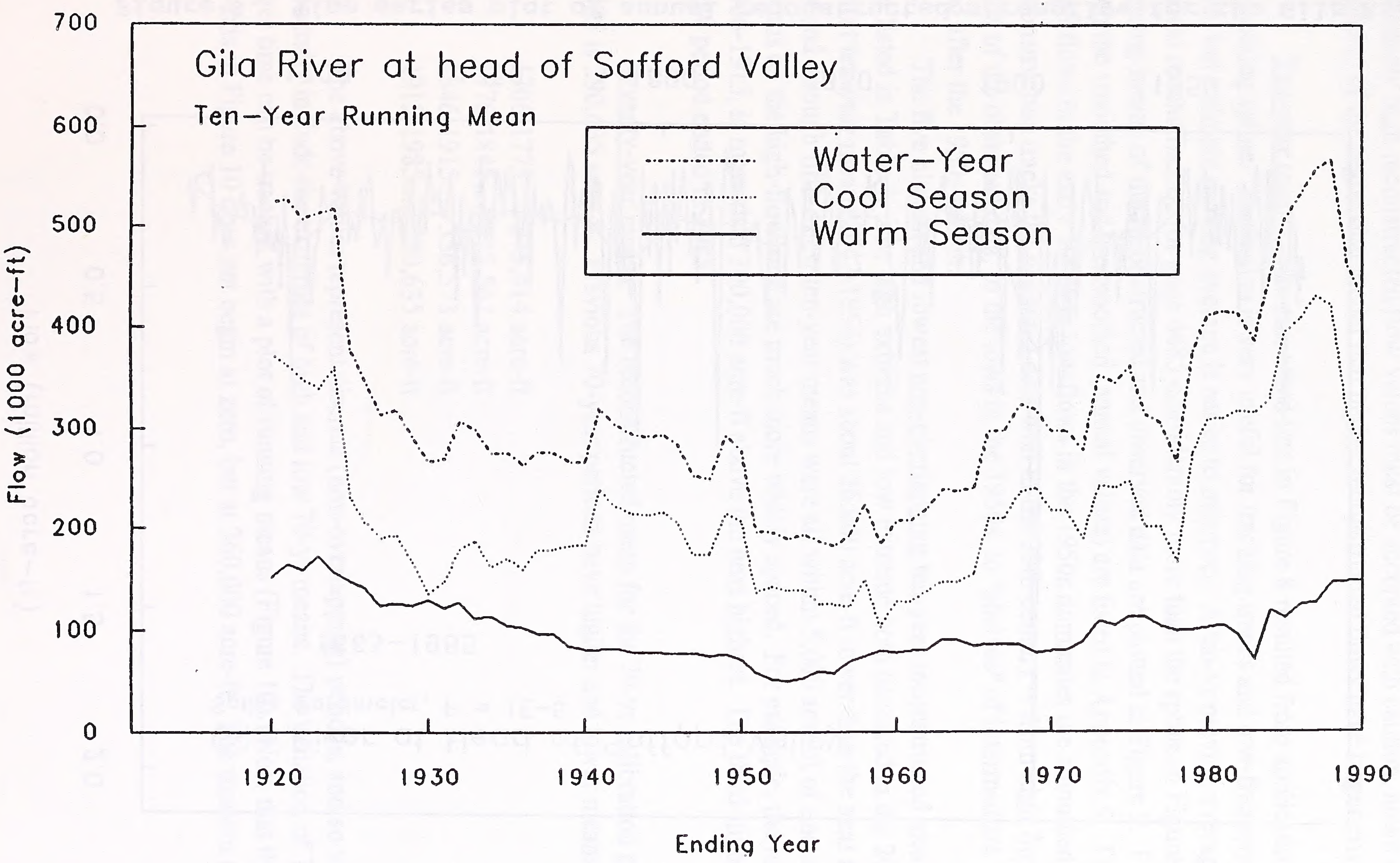

Figure 7. Ten-year running means of seasonal-total and water-year-total flow for gage 4485, the Gila River at head of Safford Valley. Some monthly data before water-year 1915, and in 1934 and 1935 have been estimated from other gaged records. The cool season is defined as November to May, warm season as June to October.

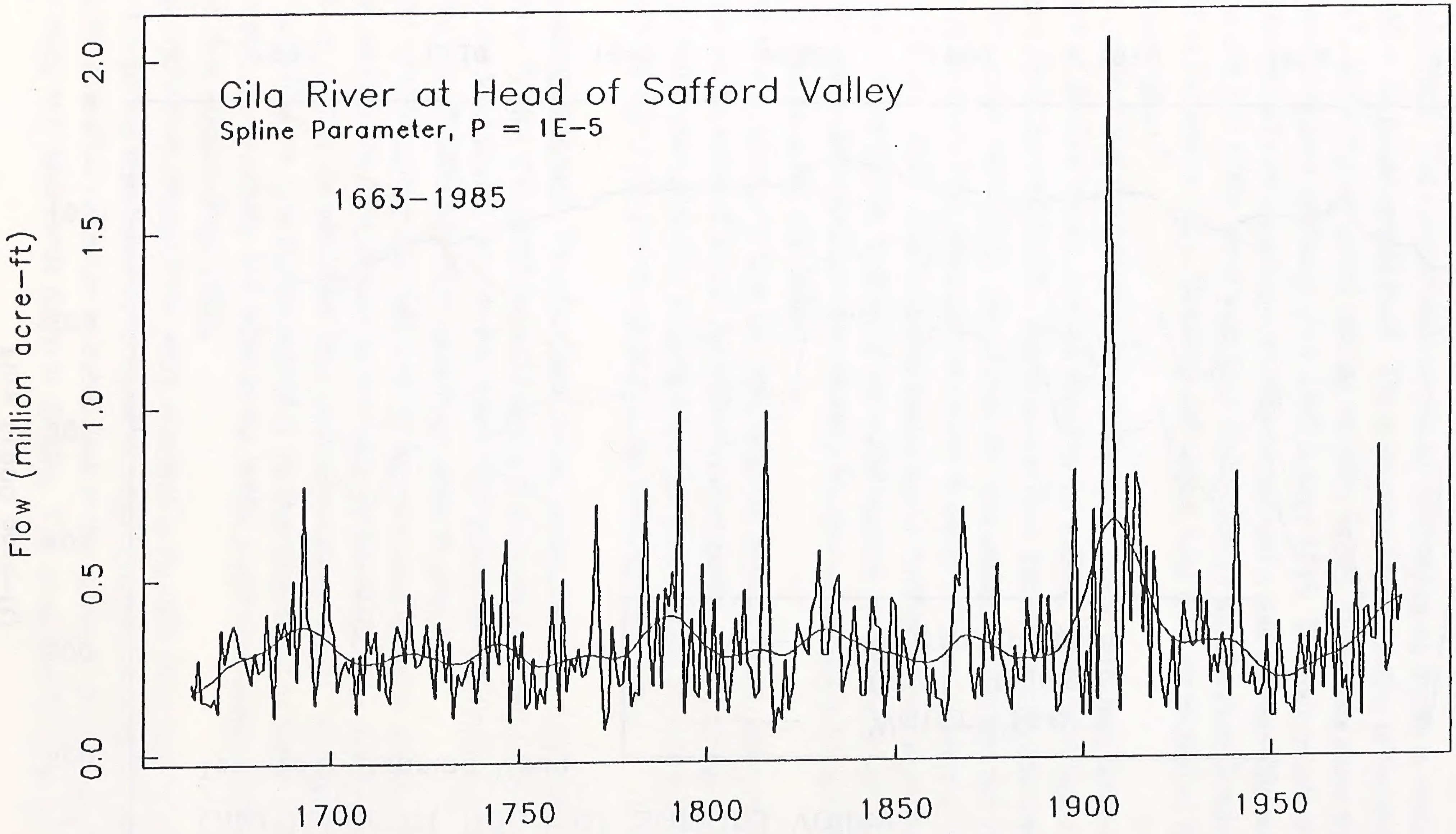

Figure 8. Time series plot of annual reconstructed streamflow for the Gila River at head of Safford Valley, 1663-1985. Smoothed line is cubic smoothing spline with smoothing parameter P=0.00001 fit to the annual series.

exceeds 2 million acre-ft -- almost double the flow for any other reconstructed water year. Extremely high reconstructed flow values must be accepted with caution, however, given the property of the regression model that higher reconstructed flows have larger errors.

Ten-year means. The smoothed line in Figure 8 resulted from application of a cubic smoothing spline. The spline is very useful for tracking trends and low-frequency variations in data, but a simple moving average is easier to interpret. A ten-yr moving average smooths the annual reconstruction for gage 4485 considerably more than the spline in Figure 7. Ten-yr running means of the reconstructed and observed data are plotted in Figure 9. For reference, both the smoothed and unsmoothed (annual values) are listed in Appendix 5. The contrast from high flows in the early 1900s to low flows in the 1950s dominates the smoothed time series. The reconstruction tracks the observed data well in the 20th century -- from high flow periods at the ends of the observed data, to the lows in the 1950s, to "shelves" of intermediate values before and after the 1950s trough.

The five highest and lowest non-overlapping ten-year reconstructed means for gage 4485 are listed in Table 4. The high extreme and low extreme both occurred in the 20th century. The driest ten-year mean (1947-1956) was about 26,000 acre-ft lower than the next driest. The second through fifth driest ten-year means were all within 5,000 acre-ft of one another. Ten-year means on the high-flow side are much more widely spaced. For example, the highest on record, 1906-1915, is more than 300,000 acre-ft above the next highest. The third-highest reconstructed flow period ended in 1985.

Seventy-year means. The reconstructed mean for the 70-yr calibration period at gage 4485 is 290,635 acre-ft. Previous 70-year periods have higher and lower means:

1706-1775.....	275,414 acre-ft
1776-1845.....	312,562 acre-ft
1846-1915.....	356,573 acre-ft
1915-1985.....	290,635 acre-ft

The above values represent discrete (non-overlapping) periods, and so would not generally include the extremes of high and low 70-yr means. The variation of 70-year means over time can be tracked with a plot of running means (Figure 10). Note that the scale along the y-axis in Figure 10 does not begin at zero, but at 260,000 acre-ft. The modern (1916-85)

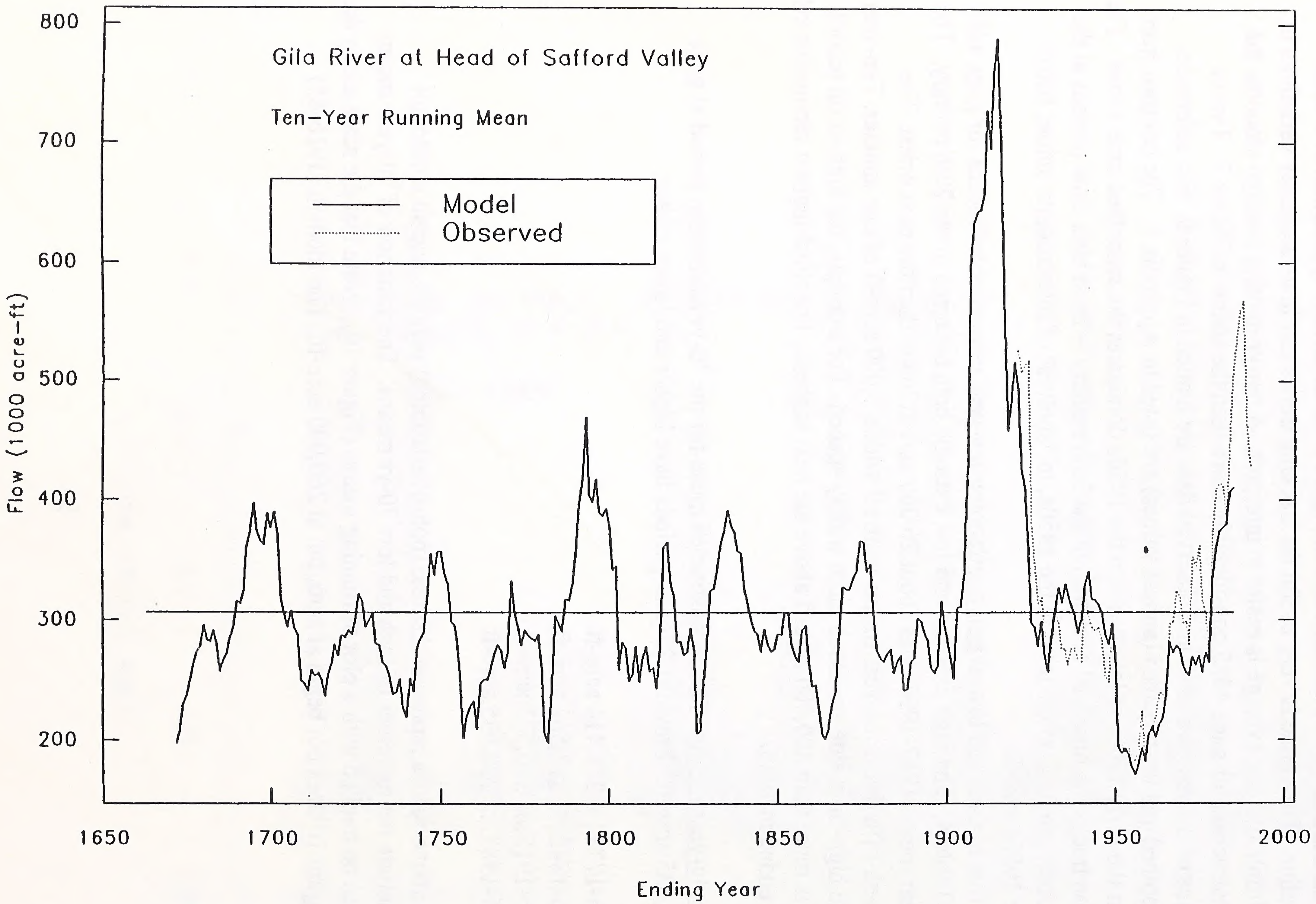

Figure 9. Ten-yr running means of annual reconstructed and observed flow of the Gila River at head of Safford Valley.

Table 4. List of five lowest and highest non-overlapping 10-yr running means of reconstructed flow of Gila River at head of Safford Valley.

LOW -FLOW		HIGH - FLOW	
Years	Flow (acre-ft)	Years	Flow (acre-ft)
1947-1956	171,596	1906-1915	788,043
1663-1672	197,317	1784-1793	468,917
1773-1782	198,432	1976-1985	410,853
1855-1864	201,022	1686-1695	397,539
1748-1757	201,954	1826-1835	391,673

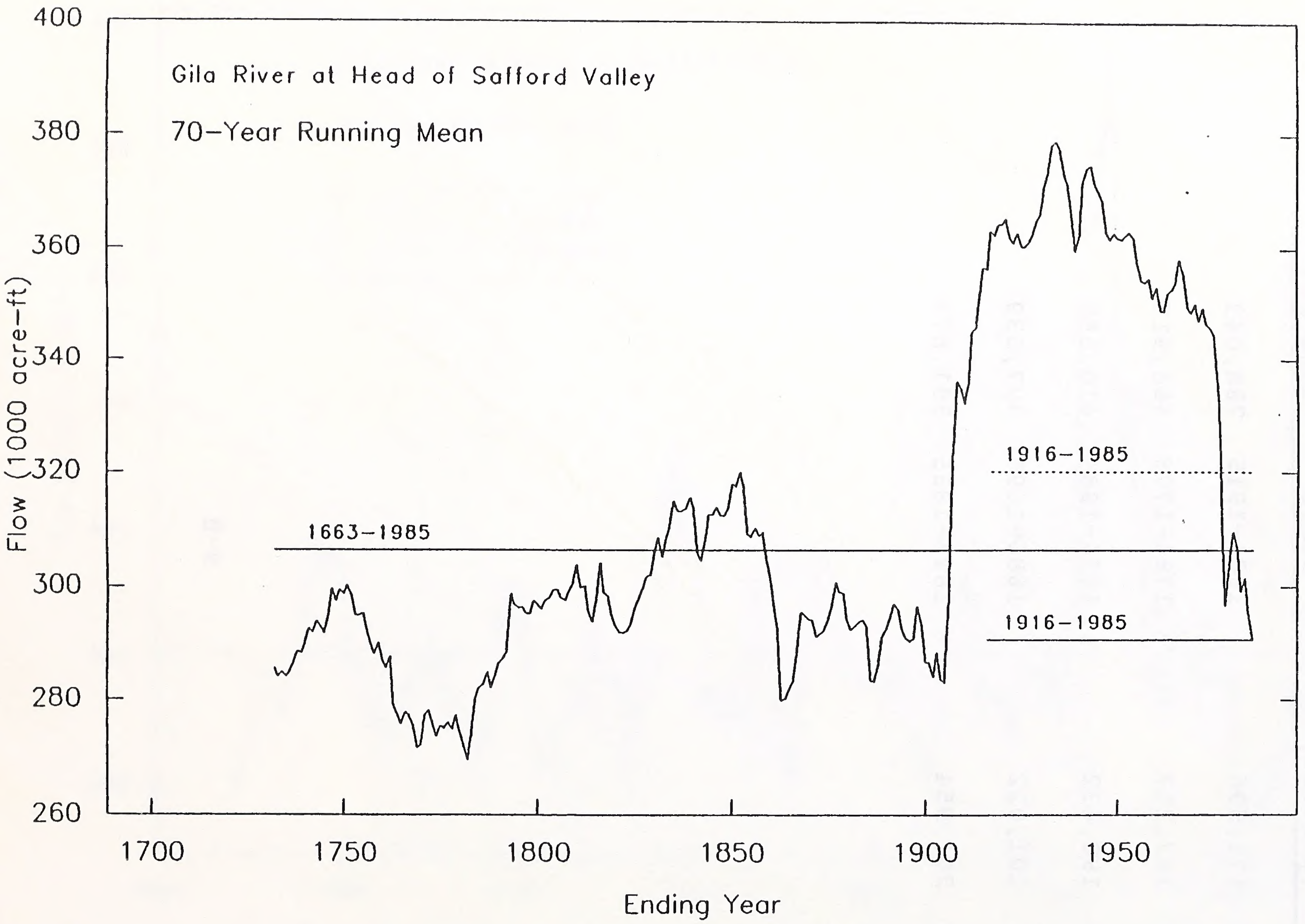

Figure 10. Running 70-yr means of reconstructed annual streamflow for Gila River at head of Safford Valley. Solid horizontal lines are long-term means of annual values over short period (1916-85) and full period (1663-1985). Offset of short horizontal lines indicates bias in reconstructed mean resulting from log-transform model.

reconstructed 70-yr mean is lower than the long-term (1663-1985) mean of the entire reconstruction, but is higher than 70-yr means occurring at times in both the 17th and 18th centuries. The highest and lowest 70-yr reconstructed means were:

1865-1934..... 378,890 acre-ft
1713-1782..... 269,627 acre-ft

The dashed line in Figure 10 marks the calibration-period mean of the observed flow. The vertical offset of the short dashed and solid lines represents the bias (mentioned earlier) due to use of a log-transform model. The reconstructed annual values should not be shifted upward to compensate for this bias, as the bias is not spread equally over the range of flows -- the bias does not apply equally to high-flow and low-flow values.

5.3 Return Periods of Low Annual Flows

The question of recurrence intervals of flows below a certain threshold can be addressed in a relative sense by comparing non-exceedance probability plots of the reconstruction over the most recent 70 yr with similar plots for the long-term reconstruction. The non-exceedance probability is the probability that annual flow is less than a specified value. Non-exceedance probability plots for the full 0-1 probability range at gage 4485 are shown in Figure 11a. The plots are best explained by example. The probability that flow is less than 0.5 million acre-ft (maf) is 0.9 in the long-term reconstruction, and about 0.81 in the calibration period. Therefore, for the flow threshold 0.5 maf, the modern period is inferred to be wet relative to the long-term period. Note that end points of the plotted lines correspond to the extreme values in the series. For example, the long-term reconstruction (solid line) peaks near 2 maf, while the calibration period reconstruction peaks near 1.2 maf.

As noted elsewhere in this report, high flows are likely to have greater reconstruction errors than low flows. If any part of Figure 11a is to be examined in detail, therefore, it should be the left hand side, corresponding to lower flows. The 0-0.5 non-exceedance probability segment of Figure 11a is shown in Figure 11b. Several observations can be made. First, from the intersections of the plotted lines with the left-hand y axis, the low extreme in reconstructed annual flow is about 50,000 acre-ft, compared to about 75,000 acre-ft in the calibration period. (The exact reconstructed values can be read from Appendix 5: 49,055 acre-ft in WY 1818; 74,399 acre-ft in WY 1971.) Second, the calibration period generally gives a higher probability of flows below any given threshold than does the long-term reconstruction. For example, the probability of an annual flow less than 200,000 acre-ft is 0.3 in the long term, but about 0.34 in the calibration period. Third, the difference between the flow values for any specified non-exceedance probability is small. This difference is given by the vertical offset between the two

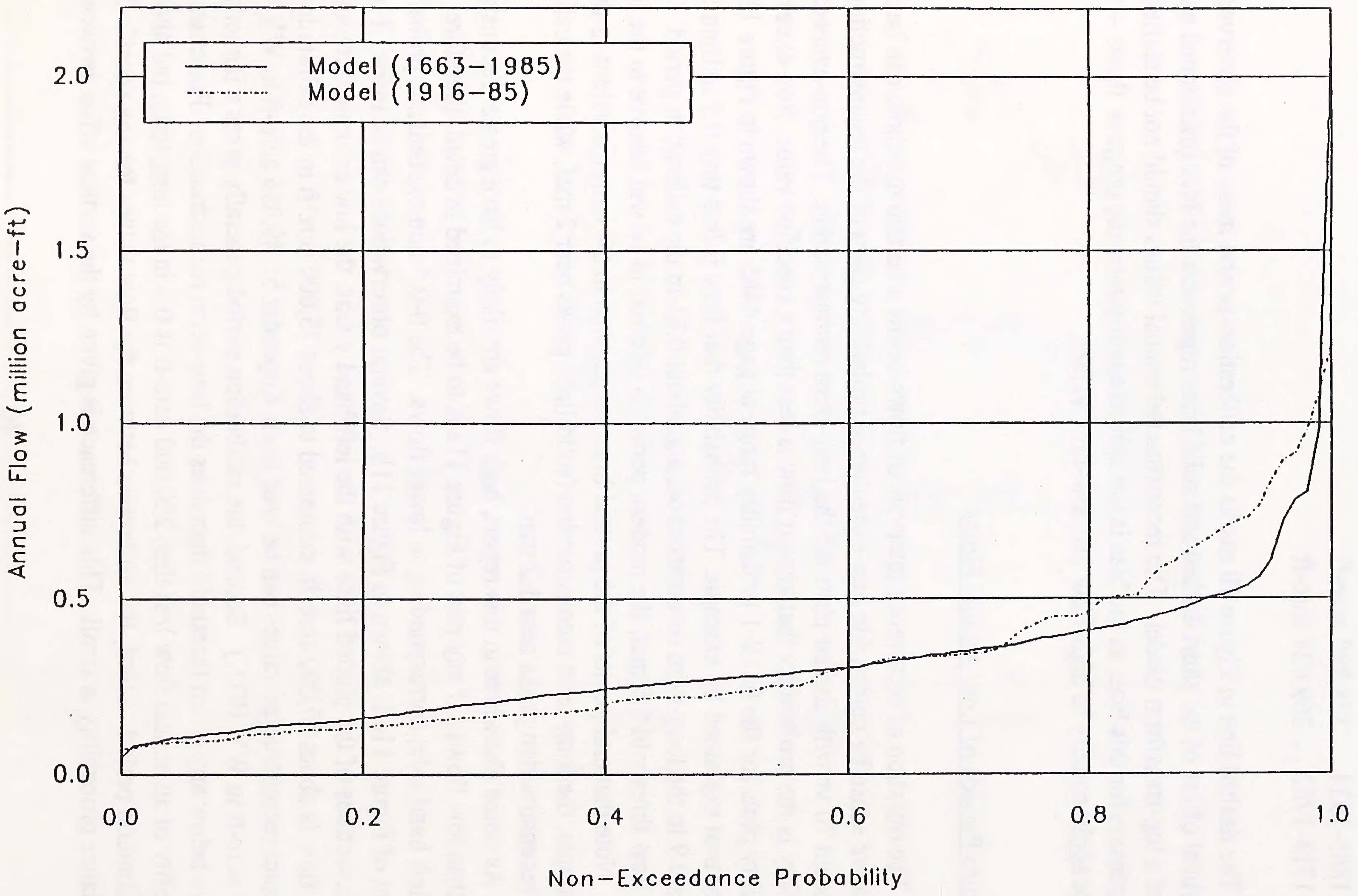

Figure 11a. Non-exceedance probabilities for various levels of annual streamflow at gage 4485 for reconstructed (model) series, modern period (1915-86) and long-term period (1663-1985).

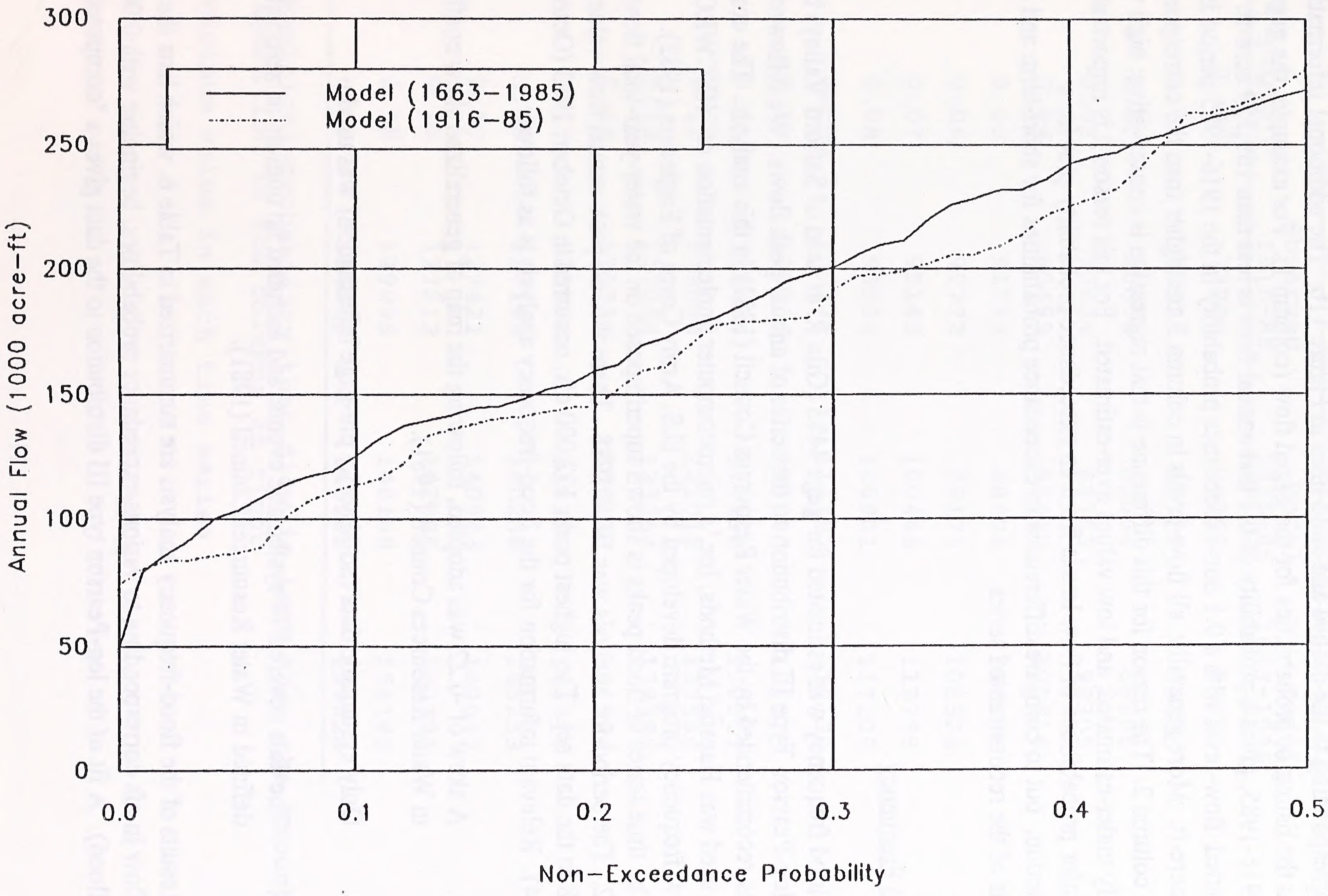

Figure 11b. Close-up of dry end of non-exceedance probability plot of Figure 11a.

lines, which is generally less than 10,000 acre-ft.

WY flow values corresponding to non-exceedance probabilities from 0.01 to 0.20 (lowest quintile of flows) for the long-term reconstruction, the calibration-period reconstruction, and the calibration period observed data are listed in Table 5. Columns 3 and 4 of Table 5 contain values corresponding to the dashed and solid lines in Figure 11b. The additional information in Table 5 is the listing of probabilities for the gaged flow (column 1). For example, the gaged record, 1916-1985, gives a probability of 0.1 that annual flow is less than 109,359 acre-ft. The reconstructed flow-level with a 0.1 non-exceedance probability in the 1916-1985 period is 113,980 acre-ft. More generally, all flow-levels in column 3 are higher than the corresponding values in column 2. The reason for this difference is that regression is conservative: high values are usually under-estimated, and low values over-estimated. For this reason it is important not to directly infer probabilities of flow levels from an exceedance probability plot for a reconstruction, but to compare differences in exceedance probabilities for short-term and long-term parts of the reconstructed series.

5.4 Flood Frequency

Flood frequency was estimated for gage 4485 (Gila R. at head of Safford Valley) by fitting a log-Pearson Type III distribution to the series of annual peak flows. We followed guidelines recommended by the Water Resources Council (1981) in this analysis. The computer software used was Haestad Methods, Inc.'s microcomputer implementation of "HECWRC", a flood-flow frequency program developed by the U.S. Army Corps of Engineers (1982).

The time series of flood peaks is shown superimposed on the water-year-total flows in Figure 12. The period for analysis was 1914-1988. There was no peak annual flow value for WY 1988 in the data set. The highest peak, 132,000 cfs, occurred in October, 1983 (October of WY 1984). Relevant information for the flood-frequency analysis is as follows:

1. A skew of -0.22 was adopted, following the map of generalized skew coefficients in Water Resources Council (1981).

2. Only systematic data (no historic, pre-gage information) was used.

3. The data covered 74 systematic events, and included no outliers or zero values as defined in Water Resources Council (1981).

Results of the flood-frequency analysis are summarized in Table 6, which lists the levels of peak flow in cfs corresponding to various exceedance probabilities, beginning with 0.002 (500-yr flood). A fit of the log-Pearson type III distribution to the data gives a "computed" flow

Table 5. Empirical non-exceedance probability for reconstructed low annual flows on the Gila River at head of Safford Valley.

	Q_c (acreft)		
$p(Q<Q_c)$[a]	Observed 1916-85	Model 1916-85	Model 1663-1986
0.00[b]	73050	74399	49055
0.01	73526	80710	79486
0.02	80078	83564	86395
0.03	90424	83763	92308
0.04	90458	85430	100214
0.05	91289	86404	103585
0.06	92772	89173	108524
0.07	95145	100443	113758
0.08	96588	106901	117200
0.09	100175	111157	119138
0.10	109359	113980	125215
0.11	112436	116198	132311
0.12	114636	122018	137586
0.13	117064	133264	139389
0.14	120318	136138	141224
0.15	123774	138357	144417
0.16	127193	140238	145233
0.17	127421	140943	148047
0.18	127812	142866	152121
0.19	129095	145160	154183
0.20	134518	145283	159628

[a] empirical probability that flow is less than the amounts specified in the columns at right

[b] minimum value in each time series

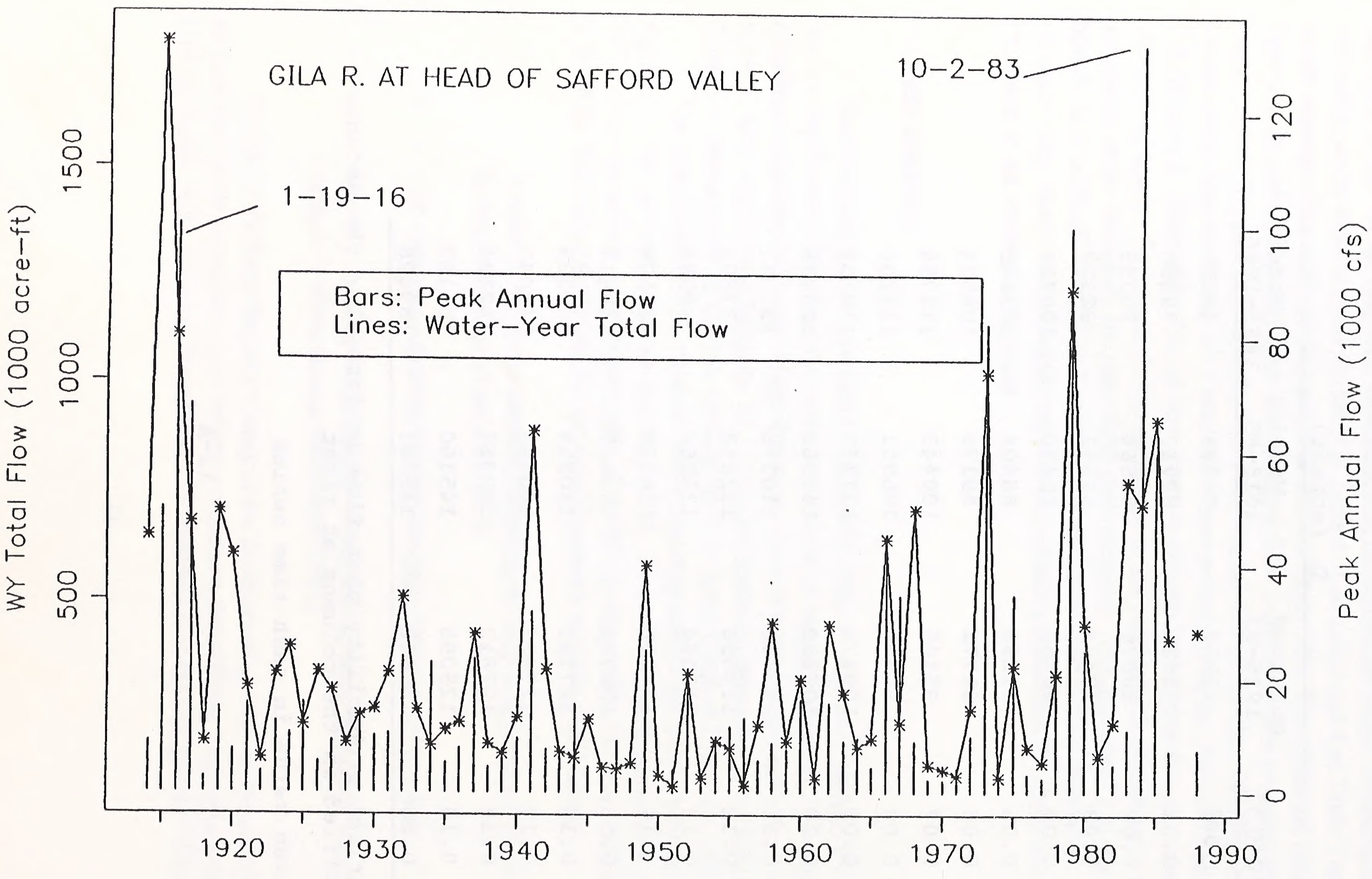

Figure 12. Time series plots of annual peak flow and water-year-total flow of Gila River at head of Safford Valley.

Table 6. Summary of flood frequency analysis for Gila River at Head of Safford Valley.

FLOW (cfs)			CONFIDENCE LIMITS	
COMPUTED	EXPECTED	$p(Q>Q_{computed})$	0.05	0.95
138,000	150,000	0.002	216,000	96,500
108,000	116,000	0.005	164,000	77,900
88,500	93,500	0.010	131,000	64,900
70,700	73,700	0.020	101,000	53,000
54,700	56,400	0.040	75,800	41,900
36,300	37,000	0.100	48,000	28,800
24,400	24,600	0.200	31,000	19,900
11,000	11,000	0.500	13,300	9,090
4,700	4,640	0.800	5,770	3,710
2,950	2,890	0.900	3,730	2,220
1,990	1,920	0.950	2,600	1,430
924	853	0.990	1,300	599

corresponding to a given exceedance probability. For example, the computed 100-yr flood is 88,500 cfs, meaning that a peak flow exceeding 88,500 cfs is likely to occur on average once in 100 yr. Alternatively, the probability is 0.01 of having a peak flow above 88,500 cfs in any given year. Uncertainty in the analysis is measured by the confidence limits in Table 6. These limits define a range within which the n-year peak flow is likely to lie at a given probability level. For example, there is a 5% chance that the 100-yr peak flow is greater than 131,000 cfs or less than 64,900 cfs. The column labeled "EXPECTED" in Table 6 reflects an expected probability adjustment to the computed cfs value in the first column. This expected probability is defined as "The average of the true probabilities of all magnitude estimates for any specified flood frequency that might be made from successive samples of a specified size" (Water Resources Council 1981). The difference between the computed and expected values in Table 6 depends on the exceedance probability and the number of events in the sample. For example, for the 100-year flood, the expected probability is $0.01 * (1.0 + 26/N^{1.16})$ (p. 11-4 in Water Resources Council (1981). As the sample size N gets larger, the estimated and computed 100-yr flood estimates converge. The decision to use the computed vs expected flows in planning is a policy decision.

The time series plots in Figure 12 show that high peak flows were generally but not always associated with high annual total flows. Water years 1915 and 1984 reveal an interesting contrast. Water-year total flow in 1915 was almost twice that in 1984, yet the flood peak in 1984 (October, 1983) was greater than twice the peak in 1915. The relationship between annual peaks and water-year totals can be conveniently summarized in a scatter plot of log-transformed values (Figure 13). Higher annual peak flows generally occur with higher annual total flows, and vice versa. The relationship for the log-transformed data is approximately linear, and highly significant (p-value less than 0.0001 for product-moment correlation coefficient). Unfortunately, the relationship is of little use for inferring magnitudes of high flood flows, because toward the right side of the figure a small vertical departure from the regression line in log units corresponds to a huge departure in cfs. For example, the highest point in Figure 13 represents a flood peak of 132,000 cfs, while the regression line would suggest an estimate near 32,000 cfs.

While inference of value of the peak annual flood from water-year total flow is fraught with difficulties, the problem is compounded if a the water-year total flow must itself be inferred from tree-ring reconstructions. Results discussed in previous sections indicate that high annual flows are poorly reconstructed. We conclude that tree-ring reconstructions cannot provide accurate estimates of peak annual flows in the Gila River. A key reason is that flood peaks sometimes result from short-duration, high intensity rainfall events -- events evoking little response in tree growth. Two possible avenues for future research are (1) to cull out flood peaks due to snowmelt and other longer-term events before relating flood series to annual streamflow totals or tree growth, and (2) to apply specialized tree-ring techniques relying not on ringwidth variations of higher elevation conifers, but on cambium scars in trees in the canyons or floodplain (McCord 1990)

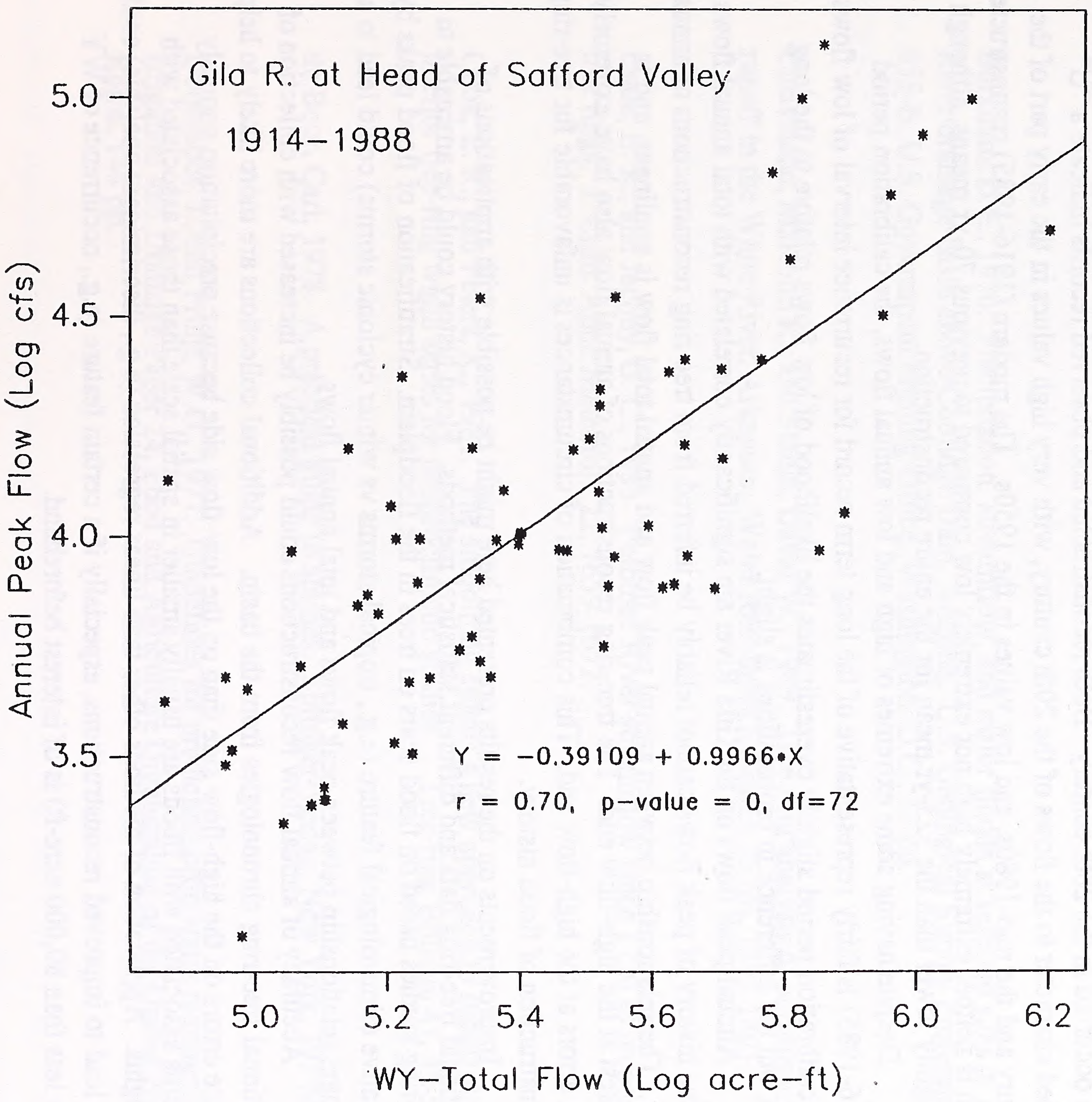

Figure 13. Scatterplot of log of annual peak flow against log of total annual flow of Gila River at head of Safford Valley.

5.5 Conclusions and Recommendations

A network of six tree-ring sites in the upper Gila River basin has yielded reconstructions of annual flow for the Gila and San Francisco Rivers to A.D. 1663. Data transformation was necessary before regression modeling. The reconstructed variable was log-10 of annual flow. Calibration statistics indicated that reconstructions account for about 66% of the variance of WY flow. Verification statistics support the accuracy implied by calibration statistics.

The reconstructions have considerable variance at decadal and longer wavelengths. The most pronounced fluctuation is a period of extremely high flows in the first two decades of the 20th century. In terms of 10-year moving averages, both the high-flow and low-flow extremes have occurred in the 20th century. Both reconstructed and observed records indicate a "U" shaped character to the flows of the 20th century, with very high values in the early part of the century and the mid-1980s, and low values in the 1950s. The modern (1916-1985) reconstructed mean is neither extremely high nor extremely low compared to previous 70-yr means, although it is slightly lower than the 323-yr mean for the entire reconstruction.

Despite having some extremes of high and low annual flows, the calibration period (1916-1985) is fairly representative of the long term record for recurrence interval of low flows. The calibration period slightly overestimates the likelihood of low flows relative to the long term, but the difference in probabilities is slight.

Annual peak flows on the Gila River are significantly correlated with total annual flows, but the history of peak flows cannot reliably be inferred from tree-ring reconstructions of annual flow. The relationship between annual peak flow and annual total flow is nonlinear, and is weakest at the high-flow end. The tree-ring reconstructions of annual flow also have extremely high errors at the high-flow end. This combination of circumstances is unfavorable for tree-ring reconstruction of flood history.

Improvements on the results presented here might be possible with applications of additional tree-ring data and different statistical methods. Flood history could be amenable to tree-ring studies based on flood scars on trees in the floodplain. Stratification of flood peaks by causative climatological feature (e.g., tropical storms vs winter cyclonic storms) could lead to a stronger relationship between peak flows and total annual flows.

Accuracy of annual flow reconstructions could possibly be increased with collection of additional tree-ring chronologies from the basin. Additional collections are more likely to help reduce errors on the high-flow side than on the low-flow side because precipitation anomaly patterns associated with floods are usually smaller in spatial scale than those associated with droughts. Application of methods other than linear regression (e.g., discriminant analysis) could also lead to improved reconstructions, especially if a certain feature (e.g., occurrence of WY flow less than 80,000 acre-ft) is of interest beforehand.

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APPENDIX 1: MONTHLY STREAMFLOW SERIES

This appendix contains listings of monthly and water-year total streamflow for four gages: Gila R. at head of Safford Valley, Gila R. near Clifton, San Francisco R. at Clifton, and San Francisco R. near Glenwood. Both gaged records and estimated missing monthly values are included. Estimated values are suffixed with "E". Annual totals are not suffixed even though some are based partly or entirely on estimated monthly values.

Column 1 is the station number (last 3 digits only). Column 2 is the water year. Columns 3-14 are the monthly values, with months listed across the top of the table. Month "10" corresponds to October, the first month of the water year. The right-most column is the annual water-year total streamflow. All values are in units of **tens of acre-ft.**

Sources of data: All non-estimated data except one segment for gage 4485 are from the EarthInfo 1991 compact-disk version of the U.S. Geological Survey database. Monthly data for the period from April of water-year 1914 to September of water-year 1920 at gage 4485 were obtained from the Bureau of Reclamation. Missing monthly values were estimated using the %U.S. Army Corp of Engineer's (1986) HEC-4 estimation procedures (See Appendix 7).

GAGE 4485: GILA R. AT HEAD OF SAFFORD VALLEY NEAR SOLOMON, AZ

STA	YEAR	10	11	12	1	2	3	4	5	6	7	8	9	TOTAL
485	1911	410E	971E	918E	2464E	2389E	8010E	2109E	732E	522E	4429E	1887E	2737E	27578
485	1912	1918E	1214E	1352E	938E	770E	9612E	4757E	2278E	836E	4986E	2068E	2215E	32944
485	1913	5058E	1963E	1703E	991E	1484E	4173E	5549E	1699E	579E	1120E	1274E	2197E	27790
485	1914	891E	2696E	2166E	1058E	1534E	2947E	1662	676	892	9054	7880	3341	34797
485	1915	9006	4677	36060	16370	21120	26350	23840	6643	1844	7248	4326	2103	159587
485	1916	1170	1310	1440	623	19800	18300	7420	4030	914	1780	5590	4820	67197
485	1917	22300	2830	1940	9210	4620	6200	4960	2580	840	1670	2540	837	60527
485	1918	702	850	1080	1240	1110	2290	1040	706	613	1180	1410	530	12751
485	1919	946	1250	1880	2490	3300	8610	11200	3800	916	7270	6950	2210	50822
485	1920	1740	1890	5050	4660	14600	6540	5750	3020	1380	937	2720	1220	49507
485	1921	777	1631	1265	1281	955	1008	755	586	551	4522	14150	2633	30114
485	1922	1151	1100	1354	1500	988	1125	1201	622	413	719	2513	923	13609
485	1923	651	942	1428	1057	915	2312	1149	664	335	2873	15365	5330	33021
485	1924	1264	3488	8035	4921	2035	2541	9793	3027	730	1451	1392	540	39217
485	1925	513	743	1026	1075	733	853	553	508	863	2147	2505	9701	21220
485	1926	2423	1276	1369	1559	1008	3962	11280	5660	867	1506	1455	1238	33603
485	1927	1384	1528	2119	1601	4260	4521	2742	1444	502	1754	3080	4583	29518
485	1928	869	917	1314	1242	1640	2720	1341	1388	397	1539	3175	776	17318
485	1929	1028	1344	1173	1094	1003	945	896	546	306	3023	9187	3132	23677
485	1930	1849	1277	1065	1102	984	3160	2721	974	462	3406	6556	1493	25049
485	1931	642	1024	1205	1119	5753	2560	3476	3565	505	1726	6310	5447	33332
485	1932	2568	1912	2829	2274	13307	11764	5343	2137	604	2855	4016	1040	50649
485	1933	1137	1023	1430	1446	3132	6249	2100	1224	1163	1389	1453	3149	24895
485	1934	1677E	1391E	1546E	2032E	1641E	913E	600E	394E	172E	754E	4186E	1386E	16692
485	1935	737E	773E	1091E	2941E	2977E	2920E	1902E	1072	492	374	2206	2836	20321

GAGE 4485 (CONT)

STA	YEAR	10	11	12	1	2	3	4	5	6	7	8	9	TOTAL
485	1936	826	1013	1414	1274	5801	2986	2664	965	423	883	1452	2129	21830
485	1937	848	1285	1365	1607	13748	11264	5512	1994	733	804	938	2137	42235
485	1938	1029	882	1197	1190	896	4130	1207	758	557	1205	1537	2525	17113
485	1939	570	833	1028	1072	974	3120	2548	675	247	427	1913	1430	14837
485	1940	2928	840	1046	1253	4787	3268	1435	739	700	818	3072	2215	23101
485	1941	1047	1668	9258	12336	12579	17582	10335	10366	1760	1394	2760	7698	88783
485	1942	7193	2412	5228	3490	2322	3522	3428	1490	470	474	1637	2413	34079
485	1943	786	900	1226	1331	1087	3876	920	497	575	1189	1517	1437	15341
485	1944	865	800	976	1018	931	837	833	570	307	953	2767	2981	13838
485	1945	976	1437	1519	1789	2281	3686	4329	1996	482	541	3048	551	22635
485	1946	1567	778	922	1216	970	855	553	373	221	686	1898	1678	11717
485	1947	842	1250	1073	1194	778	721	567	374	267	273	2737	1289	11365
485	1948	430	639	743	782	901	2785	3321	778	441	634	902	362	12718
485	1949	367	666	2820	18170	5646	14921	5896	3056	931	2107	1705	1808	58093
485	1950	828	797	1032	1094	797	868	587	374	246	1195	1103	652	9573
485	1951	668	543	602	731	717	781	583	445	213	364	1357	301	7305
485	1952	596	929	840	13413	1596	2599	5444	2619	1637	1122	1395	862	33052
485	1953	416	579	737	732	661	1910	705	467	263	1134	1208	235	9047
485	1954	263	326	438	571	569	3698	854	368	256	2669	6242	1516	17770
485	1955	1106	575	598	807	679	638	390	305	246	4434	5487	794	16059
485	1956	2167	534	666	626	708	591	405	233	117	316	797	214	7374
485	1957	246	289	369	1290	592	736	493	660	327	2404	11636	2206	21248
485	1958	1371	1217	858	843	1171	15921	12811	3499	721	440	1965	4212	45029
485	1959	3020	1343	908	933	834	611	461	285	154	1090	7181	782	17602
485	1960	690	2272	2639	9318	4235	7693	2655	1003	314	391	406	344	31960
485	1961	1095	500	642	908	804	673	737	361	254	395	1301	1372	9042
485	1962	671	2373	6201	5732	10526	3682	6652	2068	488	911	1462	3697	44463
485	1963	2635	903	2145	2130	5421	2211	1876	917	274	451	5231	4440	28634
485	1964	2116	1124	1084	1114	814	664	633	432	216	1970	2867	3306	16340
485	1965	839	703	803	1774	2202	3015	2609	1317	325	1098	1916	1778	18379
485	1966	353	591	22661	8658	3761	14888	5936	1963	572	630	2161	2157	64331
485	1967	841	838	1079	857	680	617	455	365	251	1488	11862	2509	21842
485	1968	1064	871	5274	10362	17843	15057	9426	4449	1129	1022	3622	1062	71181
485	1969	557	922	1137	1299	1277	1086	1533	619	280	681	678	2125	12194
485	1970	610	819	1167	981	768	1957	1092	779	320	675	1363	538	11069
485	1971	1269	654	791	806	610	506	380	313	201	354	2119	1735	9738
485	1972	6737	1643	2761	2808	1069	723	471	343	402	1008	1952	5274	25191
485	1973	28359	4678	4149	4143	9679	16729	16512	12530	2309	1575	1181	447	102291
485	1974	417	466	669	979	772	597	510	328	204	1117	2429	741	9229
485	1975	1257	1741	901	1103	2427	5438	5291	2156	563	1002	643	12382	34904
485	1976	1076	915	1194	1001	4574	1546	1300	1052	413	1224	871	1086	16252
485	1977	472	606	713	908	741	709	559	400	322	1500	4790	1103	12823
485	1978	636	713	706	1017	2159	20259	3740	1184	401	506	1163	616	33100
485	1979	770	13269	35651	20733	17201	13676	10957	5022	1777	887	1414	486	121843
485	1980	479	657	987	1578	22265	7515	3991	2719	834	613	1092	1964	44694
485	1981	636	771	936	1039	784	1179	886	779	403	2675	3192	1027	14307
485	1982	1464	678	923	1243	2277	5511	3213	2471	545	726	1489	1323	21863
485	1983	545	1179	6805	3936	14610	20783	12736	6847	2047	1725	1918	4383	77514
485	1984	45788	2696	5146	5385	2220	1630	1457	1081	655	1311	3581	1389	72339
485	1985	1889	1428	22883	13350	13085	18666	7890	5196	1269	1180	2007	2847	91690
485	1986	9227	3573	3532	2410	5886	5158	2751	1140	777	3073	2140	1656	41323
485	1987	2599	4029	3938	2407	2423	6978	5845	2803	1093	1420	3959	1286	38780
485	1988	891	1479	1666	2010	4699	3890	3720	2268	848	1201	10183	10002	42857
485	1989	2860	1857	1720	1928	1452	1462	955	627	444	681	1283	805	16074
485	1990	954	775	876	1153	1068	1097	763	620	400	1095	2192	1834E	12827

GAGE 4420: GILA R. NEAR CLIFTON, AZ

STA	YEAR	10	11	12	1	2	3	4	5	6	7	8	9	TOTAL
420	1911	91E	423	378	1166	816	3437	960	223	276	4541	962	1598	14871
420	1912	2059	1010	799	621	426	6549	1950	651	298	4693	1063	1066	21185
420	1913	894	683	597	551	676	1680	2620	537	228	224	421	1114	10225
420	1914	1889	1608	1469	1219	1388	1485	911	159	481	5740	4476	1814	22639
420	1915	4234	2298	14692	5238	9251	10856	10045	3089	826	3466	2425	917	67337
420	1916	517	684	683	8330	6096	6790	2751	1816	329	675	2639	2401	33711
420	1917	8232	1131	880	6597	2141	2587	2064	1026	333	226	571	207	25995
420	1918	257	386	503	582	497	1094	264	162	173	567E	647E	234E	5366
420	1919	372E	448E	1051E	2265E	1109E	2582E	3448E	1374E	295E	4713E	3491E	517E	21665
420	1920	575E	1167E	3439E	5980E	5427E	2695E	1974E	1157E	449E	329E	939E	665E	24796
420	1921	249E	820E	537E	523E	385E	452E	246E	162E	254E	1952E	8126E	1937E	15643
420	1922	435E	324E	691E	598E	353E	372E	422E	218E	146E	160E	873E	329E	4921
420	1923	184E	324E	499E	367E	613E	1221E	406E	209E	126E	1895E	6951E	3035E	15830
420	1924	936E	1369E	1987E	1822E	808E	910E	2591E	1209E	220E	309E	669E	408E	13238
420	1925	362E	327E	468E	561E	376E	515E	195E	141E	281E	1024E	1150E	4700E	10100
420	1926	1070E	504E	731E	503E	453E	1691E	4191E	2890E	315E	880E	559E	376E	14163
420	1927	854E	1141E	1492E	606E	1314E	1842E	855E	583E	134E	417E	1564E	2208E	13010
420	1928	234E	447E	487E	1164E	1085E	1323E	528	697	141	441	1017	379	7943
420	1929	494	652	614	479	449	357	173	159	100	1973	4732	1075	11257
420	1930	975	691	581	491	390	1643	1168	361	127	2011	3897	714	13049
420	1931	288	507	651	597	1728	1227	1956	1902	180	597	3151	2220	15004
420	1932	967	658	897	954	3277	3879	1826	752	206	1467	1633	376	16892
420	1933	626	513	687	742	1406	2471	727	298	523	584	596	1386	10559
420	1934	584E	1090E	563E	790E	940E	300E	202E	116E	67E	376E	1515E	338E	6881
420	1935	317E	367E	398E	1121E	1407E	1396E	546E	224	115	101	829	1416	8237
420	1936	328	535	755	688	1463	1019	648	213	132	367	621	890	7659
420	1937	326	561	631	745	4650	5576	2438	820	328	323	448	1141	17987
420	1938	501	448	621	671	401	1663	404	254	191	612	627	1597	7990
420	1939	262	479	598	601	480	1245	767	243	97	205	1051	804	6832
420	1940	2266	428	547	725	3050	2015	725	293	241	329	897	751	12267
420	1941	432	723	2887	5114	5313	6070	3929	3881	704	605	1268	5788	36714
420	1942	4883	1351	1827	1526	979	1259	1211	596	196	196	769	1490	16283
420	1943	398	521	739	736	533	1504	357	184	424	574	736	598	7304
420	1944	371	372	509	574	513	347	461	282	139	533	1812	693	6606
420	1945	452	769	779	1037	1160	1500	1641	810	190	270	1515	172	10295
420	1946	1046	328	406	672	552	407	174	111	85	163	732	613	5289
420	1947	260	639	455	636	347	292	185	95	83	103E	1167E	439E	4701
420	1948	89E	241E	372E	509E	317E	914E	1341E	269	118	250	283	103	4806
420	1949	104	261	1547	7707	3096	7511	2573	1470	390	816	762	1375	27612
420	1950	361	330	476	619	407	384	169	110	89	557	466	343	4311
420	1951	310	237	288	378	428	395	210	137	67	170	388	69	3077
420	1952	276	415	314	3183	493	937	1863	719	518	443	480	583	10224
420	1953	155	253	371	386	340	1097	211	110	72	437	437	71	3940
420	1954	77	82	148	262	240	870	227	72	67	1358	3120	687	7210
420	1955	574	233	269	449	370	272	112	76	86	2591	2596	238	7866
420	1956	1354	212	313	297	357	251	95	75	59	103	261	49	3426
420	1957	53	64	106	666	134	126	73	129	71	862	4857	874	8015
420	1958	657	507	426	472	428	6073	4835	1511	271	130	956	1680	17946
420	1959	1071	504	433	509	439	233	108	82	56	263	3497	209	7404
420	1960	98	521	567	3281	1730	3319	1086	358	79	139	103	70	11351

GAGE 4420 (CONT)

STA	YEAR	10	11	12	1	2	3	4	5	6	7	8	9	TOTAL
420	1961	362	174	273	455	392	265	228	74	81	190	636	242	3372
420	1962	196	577	2021	2244	4629	1278	2458	786	110	391	1030	1990	17710
420	1963	594	432	1361	1234	2258	833	655	262	78	79	1957	2024	11767
420	1964	499	492	463	560	414	260	129	115	68	555	758	1578	5891
420	1965	293	242	392	659	840	1200	627	398	91	363	877	1103	7085
420	1966	146	245	6980	3721	1749	6430	2525	952	238	305	1066	821	25178
420	1967	364	427	513	444	339	246	147	110	136	365	5092	1413	9596
420	1968	430	365	1587	3216	6595	8016	4717	1694	474	396	1083	390	28963
420	1969	217	393	558	735	614	471	411	169	113	268	373	963	5285
420	1970	161	291	445	449	341	804	387	140	75	202	576	282	4153
420	1971	544	214	304	403	295	180	118	89	69	125	897	910	4148
420	1972	2450	834	1021	1472	480	301	123	106	142	401	1351	4565	13246
420	1973	10784	3354	1378	1982	4915	7410	6406	5372	1018	927	455	139	44140
420	1974	146	143	322	506	380	175	129	107	74	687	1486	412	4567
420	1975	543	669	453	652	1497	2099	2285	891	175	352	217	7185	17018
420	1976	630	475	675	513	2201	637	522	358	131	395	300	460	7297
420	1977	165	327	365	461	366	219	194	110	76	514	1768	439	5004
420	1978	176	285	330	533	1140	7955	1229	499	140	210	313	202	13012
420	1979	144	3172	14234	7875	7352	5399	3644	1877	985	291	846	174	45993
420	1980	166	334	398	351	4252	1705	995	884	199	193	711	1458	11646
420	1981	250	329	315	420	320	327	168	289	128	1404	1764	236	5950
420	1982	868	227	398	651	1270	2510	1356	952	219	219	418	795	9883
420	1983	232	469	1525	975	5586	7068	5097	2311	871	665	494	761	26054
420	1984	7585	1384	2582	2771	936	588	515	363	181	411	1906	589	19811
420	1985	859	580	10217	6065	4583	7167	3422	2195	479	456	686	690	37399
420	1986	5801	1338	1458	873	2412	2091	1158	486	233	1484	1167	875	19376
420	1987	1150	1681	1726	1149	858	1695	1642	1032	370	471	1844	611	14229
420	1988	391	697	649	793	2151	1681	1150	704	239	444	5522	5614	20035
420	1989	1565	1047	907	789	618	644	373	200	138	287	737	514	7819
420	1990	575E	509E	384E	582E	560E	386E	122E	155E	154E	368E	1024E	694E	5513

GAGE 4445: SAN FRANCISCO R. AT CLIFTON, AZ

STA	YEAR	10	11	12	1	2	3	4	5	6	7	8	9	TOTAL
445	1911	216E	638	426	879E	1201E	2700E	947E	466E	253E	1657E	623E	773E	10779
445	1912	750E	409E	428E	352E	318E	3835E	2483E	1187E	421E	1441E	527E	850	13001
445	1913	1854E	1146E	733	351	662	1736	2142E	819	439	617	731	651	11881
445	1914	385	1054	602	459	372	934	446	267	212	3037	1797	1169	10734
445	1915	3512	1729	11996	6875	6980	13137	13400	3157	812	4037	1400	824	67859
445	1916	560	479	534	223E	11677	10003	3989	2276	359	840	2173	1962	35075
445	1917	12875	1045	780	2921	2139	2452	2105	1254	401	846	696	479	27993
445	1918	319	373	425	466	513	816	462	341	393	579E	548E	325E	5560
445	1919	424E	798E	901E	1043E	1464E	3711E	5318E	1971E	472E	2557E	2095E	1019E	21773
445	1920	847E	940E	2023E	1306E	5269E	2362E	3758E	1403E	660E	353E	965E	472E	20358
445	1921	343E	498E	616E	605E	394E	397E	496E	281E	255E	2543E	4095E	1106E	11629
445	1922	537E	328E	384E	569E	467E	377E	617E	300E	269E	493E	902E	281E	5524
445	1923	268E	492E	637E	477E	302E	909E	679E	396E	160E	1144E	4644E	2313E	12421
445	1924	676E	1623E	5414E	1825E	1003E	1385E	5166E	1437E	384E	701E	498E	249E	20361
445	1925	282E	257E	447E	536E	248E	390E	273E	274E	283E	1012E	926E	6550E	11478
445	1926	1200E	601E	689E	696E	515E	1790E	8439E	2937E	344E	640E	915E	696E	19462
445	1927	459E	929E	935E	593E	1811E	2269E	1577E	696E	375E	1069E	1033	2706	14452
445	1928	425	396	483	433	747	1327	711	632	219	1018	1351	329	8071
445	1929	464	491	449	439	426	490	618	332	155	725	3146	1386	9121
445	1930	576	471	442	473	442	1221	1284	442	243	1303	1629	538	9064
445	1931	290	374	392	394	1758	926	1207	1326	301	776	2039	2604	12387
445	1932	1307	854	1259	871	7293	6777	3124	1263	343	910	1860	497	26358
445	1933	438	402	518	532	1433	2752	1105	783	565	664	539	934	10665
445	1934	647E	1378E	753E	897E	630E	427E	267E	213E	101E	375E	1908E	755E	8351
445	1935	488E	271E	530E	1261E	1336E	1401E	1042E	733	346	219	888	933	9448
445	1936	369	446	584	493	1988	1378	1724	632	264	423	540	1001	9842
445	1937	413	550	489	631	5960	4479	2755	1046	357	442	387	808	18317
445	1938	473	344	416	388	344	2066	707	442	417	450	604	841	7492
445	1939	225	268	352	367	376	1531	1616	362	133	239	611	456	6536
445	1940	582	332	395	422	1484	981	561	404	311	394	1793	1303	8962
445	1941	516	781	4472	4468	4811	8039	5644	5272	941	688	1283	2049	38964
445	1942	1483	912	2616	1593	1140	1764	2042	706	238	251	743	470	13958
445	1943	346	333	437	477	429	1174	477	284	201	514	490	518	5680
445	1944	410	349	380	394	356	440	367	278	146	348	618	1001	5087
445	1945	371	520	581	596	762	1552	2148	988	245	256	1097	275	9391
445	1946	390	287	380	437	337	334	253	195	115	386	982	841	4937
445	1947	483	402	440	396	327	339	261	209	141	175	1012	423	4608
445	1948	227	275	294	312	359	1238	1794	387	323	304	350	212	6075
445	1949	204	305	1154	9314	2017	6272	2815	1353	405	924	917	421	26101
445	1950	329	338	409	369	345	393	296	200	118	513	293	211	3814
445	1951	250	194	232	263	254	270	237	231	140	195	607	170	3043
445	1952	363	387	464	8372	847	1474	3325	1580	633	491	702	281	18919
445	1953	216	270	308	294	226	758	394	275	181	597	600	132	4251
445	1954	143	184	206	228	215	2136	427	221	224	712	2048	535	7279
445	1955	408	242	260	313	238	272	216	173	148	1643	2629	378	6920
445	1956	773	224	303	289	348	287	243	146	65	175	356	128	3337
445	1957	147	168	207	498	330	451	327	458	224	986	4722	810	9328
445	1958	692	674	427	382	587	9076	7772	1654	358	281	859	2416	25178
445	1959	1569	607	441	369	351	290	280	165	115	649	3075	354	8265
445	1960	632	1338	1627	4731	1422	4176	1236	504	214	277	250	236	16643

GAGE 4445 (CONT)

STA	YEAR	10	11	12	1	2	3	4	5	6	7	8	9	TOTAL
445	1961	684	305	329	418	335	401	409	245	192	205	526	1053	5102
445	1962	478	1410	4171	2481	5816	1684	3218	1004	258	457	304	2131	23412
445	1963	1852	411	674	886	2093	966	1069	447	185	340	3419	1839	14181
445	1964	1497	640	474	385	318	310	415	264	143	1242	1321	1321	8330
445	1965	347	292	345	1012	1012	1346	1703	831	245	590	906	532	9161
445	1966	200	313	14174	3951	1471	7166	2757	1009	364	383	1002	954	33744
445	1967	492	357	443	346	315	344	291	198	183	1093	8365	1090	13517
445	1968	677	354	2459	4379	8799	6949	4653	1912	520	592	1618	451	33363
445	1969	317	391	524	609	563	640	883	481	221	351	415	869	6264
445	1970	426	467	541	447	364	833	579	485	222	301	672	280	5617
445	1971	778	313	332	313	272	308	258	189	114	215	826	565	4483
445	1972	4295	695	1768	1135	511	402	294	199	220	672	723	985	11899
445	1973	15231	1701	1369	1522	3674	7131	10308	7650	1059	706	625	264	51240
445	1974	219	272	323	456	350	331	301	167	110	348	583	357	3817
445	1975	685	734	440	408	677	3216	2423	1094	324	582	301	4855	15739
445	1976	358	350	446	407	1904	637	615	509	252	640	483	394	6995
445	1977	246	280	301	333	301	321	294	246	224	570	1319	489	4924
445	1978	320	307	314	490	590	7316	1581	593	244	238	532	343	12868
445	1979	544	8630	15031	9755	6387	6546	5771	2202	870	441	596	268	57041
445	1980	235	318	458	770	9376	3457	2705	1745	497	353	738	635	21287
445	1981	316	323	337	410	383	760	517	366	205	726	1002	541	5886
445	1982	411	281	330	435	702	1902	1061	839	246	286	618	467	7578
445	1983	238	581	3128	1528	5565	9427	6581	3022	849	656	897	2799	35271
445	1984	26345	1436	1625	2310	926	771	770	614	366	625	1181	819	37788
445	1985	1016	735	9208	4277	4076	8389	3895	2405	542	377	963	1374	37257
445	1986	2141	871	1192	850	2540	1798	1190	602	354	1203	720	525	13986
445	1987	1027	1847	1527	1028	1293	4497	3592	1501	495	722	1780	526	19835
445	1988	454	687	827	966	2467	2007	2407	1178	406	441	3932	3595	19367
445	1989	990	711	725	928	671	800	478	300	181	424	466	390	7064
445	1990	412	327	341	546E	395	449	381	341	220	483	1187	817E	5899

GAGE 4440: SAN FRANCISCO R. NEAR GLENWOOD, NM

STA	YEAR	10	11	12	1	2	3	4	5	6	7	8	9	TOTAL
440	1911	127E	514E	377E	335E	432E	712E	296E	172E	106E	784E	275E	389E	4519
440	1912	492E	135E	123E	215E	166E	2208E	1192E	728E	272E	434E	260E	283E	6508
440	1913	216E	329E	354E	178E	296E	917E	1325E	276E	161E	403E	286E	244E	4985
440	1914	281E	408E	485E	285E	146E	431E	260E	170E	145E	661E	810E	700E	4782
440	1915	517E	382E	4052E	931E	2834E	4846E	6405E	1331E	351E	686E	653E	273E	23261
440	1916	410E	203E	268E	150E	2153E	5187E	2725E	1169E	344E	289E	798E	509E	14205
440	1917	644E	428E	453E	945E	1319E	1061E	887E	674E	272E	195E	386E	314E	7578
440	1918	145E	143E	146E	201E	233E	249E	160E	191E	161E	304E	324E	82E	2339
440	1919	175E	386E	326E	260E	461E	1015E	2268E	1748E	297E	381E	611E	389E	8317
440	1920	647E	535E	434E	662E	1252E	836E	1649E	532E	271E	233E	517E	245E	7813
440	1921	131E	229E	279E	225E	132E	160E	150E	146E	116E	484E	1694E	274E	4020
440	1922	235E	172E	170E	222E	194E	86E	193E	122E	99E	202E	367E	218E	2280
440	1923	136E	206E	308E	244E	114E	331E	207E	167E	90E	438E	1476E	441E	4158
440	1924	263E	1049E	2308E	624E	456E	662E	2839E	604E	216E	222E	135E	67E	9445
440	1925	196E	113E	129E	159E	128E	186E	81E	146E	109E	335E	323E	2069E	3974
440	1926	273E	148E	154E	200E	179E	1085E	4213E	1370E	344E	326E	271E	256E	8819
440	1927	130E	316E	211E	189E	617E	1234E	720E	315E	185E	343E	275E	662E	5197
440	1928	246	210	194	188	253	511	335	327	114	317	415	179	3289
440	1929	210	221	196	191	182	191	208	144	105	311	633	333	2925
440	1930	299	167	183	222	198	708	806	230	134	665	513	364	4489
440	1931	155	171	142	142	498	230	581	698	150	263	877	919	4826
440	1932	335	294	341	300	2717	3382	1726	676	182	430	677	238	11298
440	1933	207	200	204	181	389	1140	431	331	244	389	382	316	4414
440	1934	299	338	301	193	168	120	112	108	69	172	994	281	3155
440	1935	155	152	176	406	379	598	391	262	165	114	445	326	3569
440	1936	218	190	223	170	333	521	684	276	121	209	279	379	3603
440	1937	216	225	214	189	2039	2290	1160	446	141	168	165	258	7511
440	1938	219	172	171	156	137	612	234	169	176	255	211	431	2943
440	1939	119	123	146	164	159	917	686	157	84	110	301	222	3188
440	1940	250	165	169	173	372	523	236	191	116	280	1084	612	4171
440	1941	262	249	1484	1510	2208	4111	3048	2797	482	353	483	726	17713
440	1942	606	471	900	662	467	883	950	346	162	171	411	181	6210
440	1943	202	186	233	227	186	208	140	164	116	237	311	173	2383
440	1944	270	198	191	181	165	209	136	116	108	196	318	395	2483
440	1945	175	184	205	193	278	719	839	372	126	151	523	161	3926
440	1946	210	158	185	162	139	137	103	104	64	184	628	503	2577
440	1947	280	196	191	169	131	114	83	95	79	93	443	143	2017
440	1948	102	133	132	136	181	820	994	136	95	172	129	68	3098
440	1949	104	152	521	2727	761	3258	1419	632	225	389	365	222	10775
440	1950	181	180	186	190	148	138	105	95	63	293	135	105	1819
440	1951	137	84	112	129	134	102	91	113	89	102	387	94	1574
440	1952	164	151	178	2674	319	492	1596	683	299	224	236	136	7152
440	1953	90	138	167	145	115	210	116	112	93	156	171	55	1568
440	1954	74	72	80	115	104	642	115	130	128	221	930	170	2781
440	1955	137	105	107	125	114	86	61	58	73	467	845	114	2292
440	1956	187	74	88	83	86	87	62	53	34	100	113	46	1013
440	1957	64	64	83	124	93	101	61	178	102	207	2409	314	3800
440	1958	228	227	137	117	130	2950	3292	836	150	107	261	646	9081
440	1959	308	198	142	135	104	70	80	69	56	324	851	130	2467
440	1960	228	435	436	1030	465	1895	490	220	115	117	84	85	5600

GAGE 4440 (CONT)

STA	YEAR	10	11	12	1	2	3	4	5	6	7	8	9	TOTAL
440	1961	257	130	114	114	97	136	138	127	91	91	204	408	1907
440	1962	274	285	715	650	2499	790	1688	435	141	146	97	212	7932
440	1963	249	179	264	217	463	248	297	162	82	81	600	453	3295
440	1964	285	209	195	159	115	79	67	88	79	339	548	979	3142
440	1965	155	140	170	387	394	576	752	314	125	407	358	323	4101
440	1966	60	131	3643	1301	379	3895	1375	478	195	163	346	402	12368
440	1967	224	153	172	147	93	102	101	103	74	361	1995	425	3950
440	1968	187	141	448	1538	3331	3471	2516	1105	277	155	656	220	14045
440	1969	156	189	199	244	202	212	255	181	136	169	239	409	2591
440	1970	153	199	198	226	119	249	173	256	149	227	303	102	2354
440	1971	182	138	132	158	111	119	90	93	74	148	521	374	2140
440	1972	2655	162	1063	560	242	138	126	112	103	263	302	405	6131
440	1973	6581	716	495	506	1197	3982	6240	3645	556	369	252	144	24683
440	1974	113	166	177	208	160	127	108	112	85	105	164	157	1682
440	1975	326	301	180	184	273	1591	1430	544	182	297	171	1676	7155
440	1976	115	118	155	157	866	288	210	232	162	214	140	218	2875
440	1977	115	118	155	162	140	136	109	138	117	245	556	279	2270
440	1978	197	179	144	157	198	2887	679	325	159	135	225	138	5423
440	1979	155	3093	6568	3129	3343	3857	2971	1160	482	221	288	152	25419
440	1980	132	146	190	279	2873	1347	1025	754	204	160	257	245	7612
440	1981	143	126	139	196	164	213	125	199	125	198	313	237	2178
440	1982	174	135	128	183	189	631	422	399	140	135	193	153	2882
440	1983	117	238	726	387	2233	4023	3181	1609	456	205	458	1214	14847
440	1984	12459	447	466	644	295	300	275	291	213	304	608	231	16533
440	1985	330	340	5292	1838	2093	6370	2075	1163	308	235	411	516	20971
440	1986	872	432	391	311	1210	811	544	241	135	652	296	172	6067
440	1987	515	941	658	372	512	2854	2385	902	283	324	884	323	10953
440	1988	268	387	393	371	964	986	1109	578	192	256	1871	2192	9567
440	1989	536	380	382	440	360	293	191	161	117	182	172	145	3359
440	1990	170	166	175	209	189	181	160	183	149	234E	429E	316E	2561

APPENDIX 2: HECWRC OUTPUT

This appendix lists input and output for the U.S. Army Corps of Engineers HECWR
flood frequency program as run on gage 4485, Gila River at head of Safford Valley.

```
***********************************************************                     ***************************************
*  FLOOD FLOW FREQUENCY ANALYSIS                          *                     *  U.S. ARMY CORPS OF ENGINEERS        *
*  WATER RESOURCES COUNCIL VERSION                        *                     *  THE HYDROLOGIC ENGINEERING CENTER
*  MODIFICATION 02 - ERROR CORRECTION 03 (04 HMI 4/90*                          *  609 SECOND STREET, SUITE D
*  VERSION DATE - DECEMBER 1983  (BULLETIN 17B)           *                     *  DAVIS, CALIFORNIA 95616             *
*  RUN DATE: 10/08/92           TIME: 18:18:51            *                     *                                      *
***********************************************************                     ***************************************
```

```
X     X  XXXXXXX   XXXXX   X     X  XXXXXX    XXXXX
X     X  X        X     X  X     X  X     X  X     X
X     X  X        X        X     X  X     X  X
XXXXXXX  XXXXX    X        X  X  X  XXXXXX   X
X     X  X        X        X X X X  X   X    X
X     X  X        X     X  XX   XX  X    X   X     X
X     X  XXXXXXX   XXXXX   X     X  X     X   XXXXX
```

```
:::::::::::::::::::::::::::::::::::::::::::
:::::::::::::::::::::::::::::::::::::::::::
:::                                     :::
:::  Full Microcomputer Implementation  :::
:::                 by                  :::
:::         Haestad Methods, Inc.       :::
:::                                     :::
:::::::::::::::::::::::::::::::::::::::::::
:::::::::::::::::::::::::::::::::::::::::::

    37 Brookside Road * Waterbury, Connecticut  06708 * (203) 755-1666
```

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^H ************************************
* FLOOD FLOW FREQUENCY ANALYSIS  *
* VERSION DATE  --  DEC 12, 1983 *
* AFTER BULLETIN 17B, SEPT 1981  *
**********************************


**TITLE CARD(S)**
TT    Drainage Area  7896.0        Hydrolog Unit 15040005
TT    County: 009  Contribute Area          0.0        Years          1914-1988
TT    Latitude  32:52:06  Gage Datum 3064.88         Continuous     No  /No
TT    Longitude   109:30:38  Base Flow :4000.0        Ann/Part  Cnt 74  /205

**JOB CARD(S)**
     IPPC   ISKFX  IPROUT    IFMT    IWYR   IUNIT   ISMRY   IPNCH    IREG
J1     3      3       0       0       0       0       0       0       0

**STATION IDENTIFICATION**
ID    GILA River AT HEAD OF SAFFORD VALLEY NR SOLOMON ARI, Id: 09448500
```

```
**GENERALIZED SKEW**
     ISTN   GGMSE    SKEW
GS            .000    -.22


 FINAL RESULTS
-PLOTTING POSITIONS-  GILA River AT HEAD OF SAFFORD VALLEY NR SOLO
****************************************************************
*.....EVENTS ANALYZED......*...........ORDERED EVENTS..........*
*                          *          WATER               HAZEN *
* MON  DAY  YEAR  FLOW,CFS  *   RANK   YEAR   FLOW,CFS PLOT POS *
*--------------------------*-----------------------------------*
*  21    8  1914    9000.  *      1   1984    132000.    .0068 *
*  20   12  1915   50000.  *      2   1917    100000.    .0203 *
*  19    1  1916  100000.  *      3   1980    100000.    .0338 *
*  14   10  1917   67900.  *      4   1974     82400.    .0473 *
*   1    7  1918    2700.  *      5   1918     67900.    .0608 *
*   3    8  1919   15000.  *      6   1986     60200.    .0743 *
*   5   12  1920    7620.  *      7   1916     50000.    .0878 *
*  21    8  1921   15700.  *      8   1967     43000.    .1014 *
*  15    8  1922    3780.  *      9   1975     35000.    .1149 *
*  12    8  1923   12600.  *     10   1968     34800.    .1284 *
*  28   12  1924   10600.  *     11   1942     31900.    .1419 *
*   3    9  1925   15900.  *     12   1981     25300.    .1554 *
*   7    4  1926    5660.  *     13   1950     25200.    .1689 *
*  13    9  1927    9320.  *     14   1933     24000.    .1824 *
*   1    8  1928    3230.  *     15   1937     23700.    .1959 *
*  30    7  1929   12700.  *     16   1935     23000.    .2095 *
*  11    8  1930   10100.  *     17   1978     21600.    .2230 *
*  15    2  1931   10500.  *     18   1953     19700.    .2365 *
*  10    2  1932   24000.  *     19   1961     16700.    .2500 *
*   9    9  1933    9600.  *     20   1963     16100.    .2635 *
*  27    8  1934   23000.  *     21   1925     15900.    .2770 *
*   1    9  1935    5550.  *     22   1945     15800.    .2905 *
*  17    2  1936    8000.  *     23   1922     15700.    .3041 *
*   8    2  1937   23700.  *     24   1919     15000.    .3176 *
*   4    3  1938    4690.  *     25   1956     13300.    .3311 *
*   6    8  1939    7370.  *     26   1930     12700.    .3446 *
*   6    9  1940    9840.  *     27   1924     12600.    .3581 *
*  30    9  1941   31900.  *     28   1956     11700.    .3716 *
*  12   12  1942    7730.  *     29   1984     11300.    .3851 *
*  27    9  1943    6680.  *     30   1925     10600.    .3986 *
*  25    9  1944   15800.  *     31   1932     10500.    .4122 *
*  11    8  1945    4820.  *     32   1973     10200.    .4257 *
*   9   10  1946    5100.  *     33   1931     10100.    .4392 *
*  30    8  1947    9250.  *     34   1965      9880.    .4527 *
*   1    6  1948    2540.  *     35   1955      9850.    .4662 *
*  14    1  1949   25200.  *     36   1940      9840.    .4797 *
*  30    7  1950    1240.  *     37   1933      9600.    .4932 *
*   3    8  1951    4240.  *     38   1964      9350.    .5068 *
*  19    1  1952   19700.  *     39   1928      9320.    .5203 *
*  30    7  1953    3040.  *     40   1969      9280.    .5338 *
*  24    3  1954    9850.  *     41   1948      9250.    .5473 *
*  24    7  1955   11700.  *     42   1959      9060.    .5608 *
*   4   10  1956   13300.  *     43   1915      9000.    .5743 *
*  26    7  1957    5980.  *     44   1937      8000.    .5878 *
*  23    3  1958    9060.  *     45   1960      7860.    .6014 *
*  28    8  1959    7860.  *     46   1989      7820.    .6149 *
*  12    1  1960   16700.  *     47   1943      7730.    .6284 *
*  10    9  1961    4800.  *     48   1987      7690.    .6419 *
*  26    9  1962   16100.  *     49   1920      7620.    .6554 *
*  19   10  1963    9350.  *     50   1939      7370.    .6689 *
*  15    7  1964    9880.  *     51   1982      7000.    .6824 *
*   2    8  1965    4800.  *     52   1944      6680.    .6959 *
*  22   12  1966   43000.  *     53   1958      5980.    .7095 *
*  12    8  1967   34800.  *     54   1926      5660.    .7230 *
*  20  12  1968     9280.   *    55    1935       5550.    .7365   *
*  11   9  1969     2460.   *    56    1982       5240.    .7500   *
*   6   8  1970     2250.   *    57    1946       5100.    .7635   *
*   3  10  1971     4510.   *    58    1946       4820.    .7770   *
*  25  10  1972    10200.   *    59    1962       4800.    .7905   *
*  20  10  1973    82400.   *    60    1965       4800.    .8041   *
*  16   8  1974     3280.   *    61    1938       4690.    .8176   *
*   9   9  1975    35000.   *    62    1971       4510.    .8311   *
*  11   2  1976     3400.   *    63    1951       4240.    .8446   *
*  13   8  1977     2540.   *    64    1923       3780.    .8581   *
*   2   3  1978    21600.   *    65    1977       3400.    .8716   *
*  19  12  1979   100000.   *    66    1975       3280.    .8851   *
*  16   2  1980    25300.   *    67    1928       3230.    .8986   *
*  12   7  1981     7000.   *    68    1954       3040.    .9122   *
*   3  10  1982     5240.   *    69    1918       2700.    .9257   *
*  25   3  1983    11300.   *    70    1948       2540.    .9392   *
*   2  10  1984   132000.   *    71    1978       2540.    .9527   *
*  29  12  1985    60200.   *    72    1970       2460.    .9662   *
*  17  10  1986     7690.   *    73    1970       2250.    .9797   *
*  23   9  1988     7820.   *    74    1951       1240.    .9932   *
*********************************************************************

-OUTLIER TESTS  -
---------------------------------------------------------------------
LOW OUTLIER TEST
----------------

BASED ON  74 EVENTS, 10 PERCENT OUTLIER TEST VALUE K(N) = 2.912

       0 LOW OUTLIER(S) IDENTIFIED BELOW TEST VALUE OF     608.6


-----------------
HIGH OUTLIER TEST
-----------------

BASED ON  74 EVENTS, 10 PERCENT OUTLIER TEST VALUE K(N) = 2.912

      0 HIGH OUTLIER(S) IDENTIFIED ABOVE TEST VALUE OF  184444.

---------------------------------------------------------------------


-SKEW WEIGHTING -
---------------------------------------------------------------------
BASED ON  74 EVENTS, MEAN-SQUARE ERROR OF STATION SKEW =-99.000
DEFAULT OR INPUT MEAN-SQUARE ERROR OF GENERALIZED SKEW =    .302
---------------------------------------------------------------------
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 FINAL RESULTS
-FREQUENCY CURVE-  GILA River AT HEAD OF SAFFORD VALLEY NR SOLO
***************************************************************
*........FLOW,CFS.......*             *...CONFIDENCE LIMITS...*
*              EXPECTED * EXCEEDANCE  *                       *
*  COMPUTED PROBABILITY * PROBABILITY *  .05 LIMIT  .95 LIMIT *
*-----------------------*-------------*-----------------------*
*   138000.    150000.  *    .002     *   216000.     96500.  *
*   108000.    116000.  *    .005     *   164000.     77900.  *
*    88500.     93500.  *    .010     *   131000.     64900.  *
*    70700.     73700.  *    .020     *   101000.     53000.  *
*    54700.     56400.  *    .040     *    75800.     41900.  *
*    36300.     37000.  *    .100     *    48000.     28800.  *
*    24400.     24600.  *    .200     *    31000.     19900.  *
*    11000.     11000.  *    .500     *    13300.      9090.  *
*     4700.      4640.  *    .800     *     5770.      3710.  *
*     2950.      2890.  *    .900     *     3730.      2220.  *
*     1990.      1920.  *    .950     *     2600.      1430.  *
*      924.       853.  *    .990     *     1300.       599.  *
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*
*   FREQUENCY CURVE STATISTICS   *     STATISTICS BASED ON    *
*--------------------------------*----------------------------*
*  MEAN LOGARITHM        4.0251  *  HISTORIC EVENTS         0 *
*  STANDARD DEVIATION     .4261  *  HIGH OUTLIERS      0      *
*  COMPUTED SKEW          .5349  *  LOW OUTLIERS       0      *
*  GENERALIZED SKEW     -.2200  *  ZERO OR MISSING    0      *
*  ADOPTED SKEW         -.2200  *  SYSTEMATIC EVENTS     74 *
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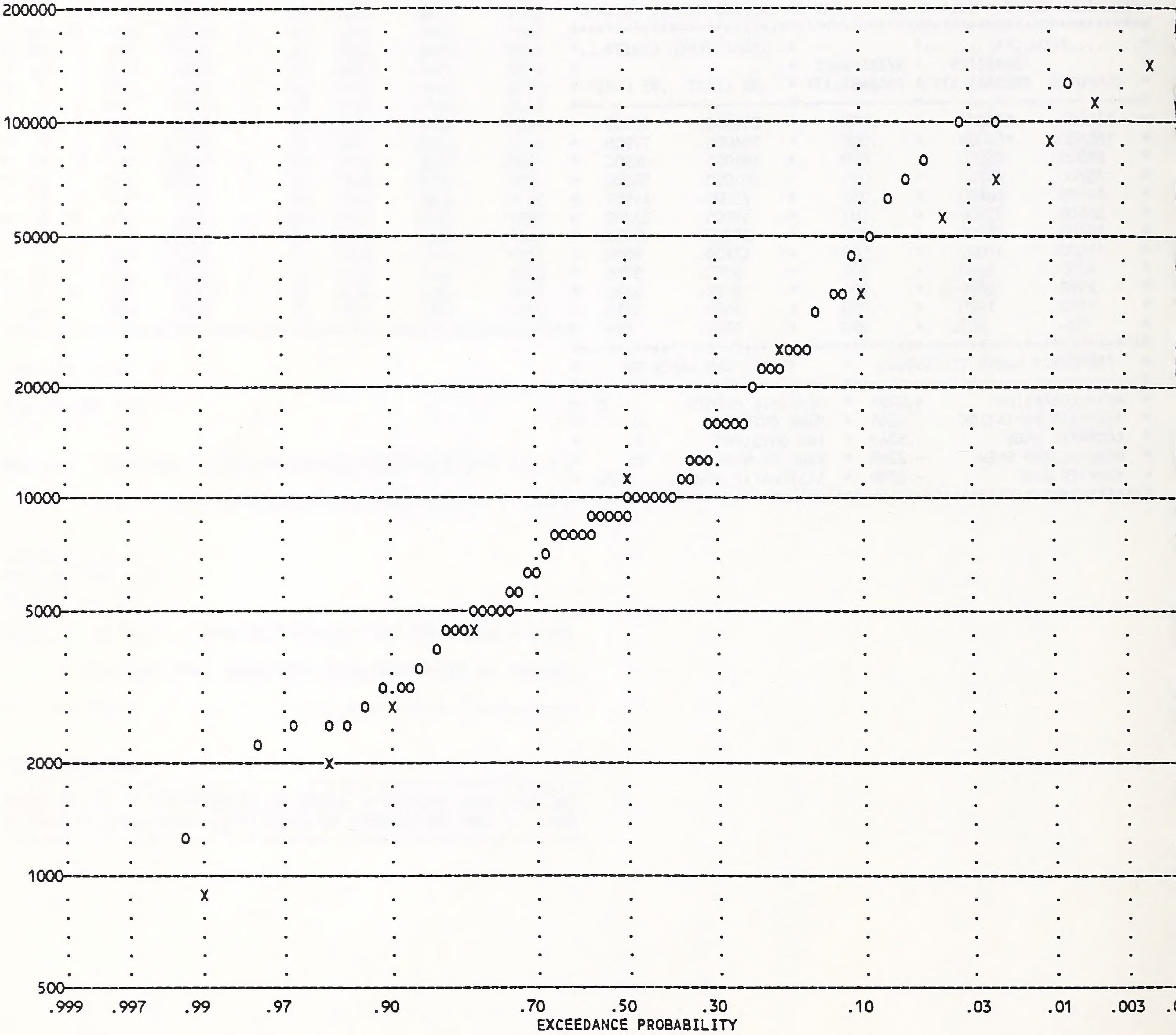
FINAL RESULTS
-FREQUENCY PLOT -  GILA River AT HEAD OF SAFFORD VALLEY NR SOLOMON ARI, Id: 09448500
BASED ON COMPUTED VALUES, FLOW IN CUBIC FEET PER SECOND
```



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LEGEND - O=OBSERVED EVENT, H=HIGH OUTLIER OR HISTORIC EVENT, L=LOW OUTLIER, Z=ZERO OR MISSING X=COMPUTED CURVE
```
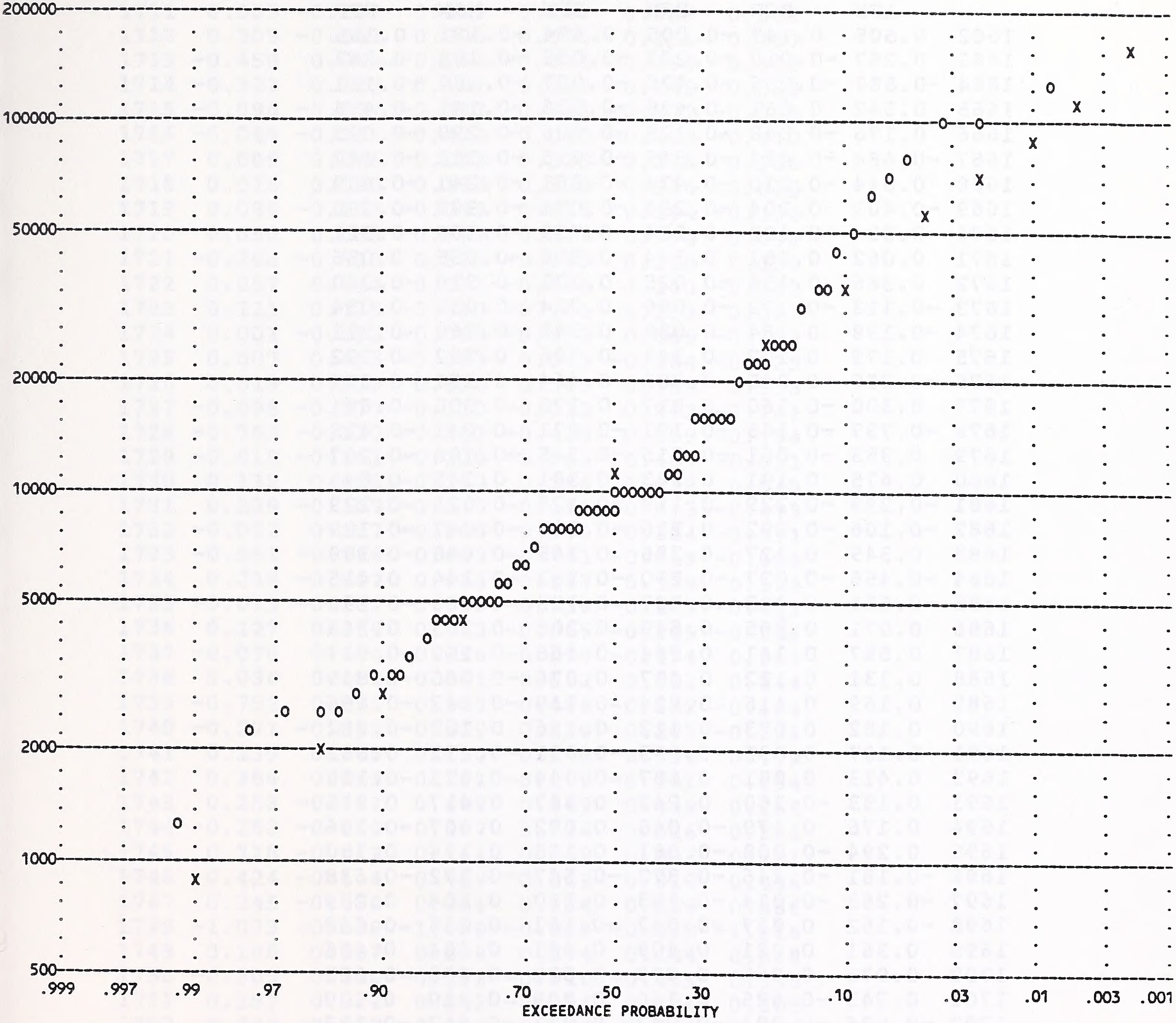

FINAL RESULTS
-FREQUENCY PLOT - GILA River AT HEAD OF SAFFORD VALLEY NR SOLOMON ARI, Id: 09448500
BASED ON EXPECTED PROBABILITY ADJUSTMENT, FLOW IN CUBIC FEET PER SECOND



LEGEND - O=OBSERVED EVENT, H=HIGH OUTLIER OR HISTORIC EVENT, L=LOW OUTLIER, Z=ZERO OR MISSING X=COMPUTED CURVE

APPENDIX 3: LISTINGS OF TREE-RING CHRONOLOGIES (RESIDUAL)

	AFN	BCR	BKM	EPN	MJN	RPP
1662	0.505	0.149	-0.005	0.474	-0.131	0.155
1663	0.257	-0.010	-0.273	-0.055	-0.194	0.243
1664	-0.887	-0.255	-0.475	-0.067	-0.482	-0.151
1665	0.542	0.061	0.438	-0.126	-0.141	0.455
1666	0.176	-0.048	-0.175	-0.606	-0.299	-0.023
1667	-0.484	-0.484	-0.345	-0.716	-0.318	-0.447
1668	0.044	-0.210	-0.474	-0.361	-0.241	-0.409
1669	-0.403	0.204	-0.296	-0.074	-0.193	-0.390
1670	-0.334	-0.182	-0.254	-0.719	-0.266	-0.521
1671	0.062	0.181	0.344	0.396	-0.035	0.036
1672	0.366	0.154	-0.025	0.171	0.319	-0.260
1673	-0.113	-0.172	-0.009	0.024	0.035	0.054
1674	-0.198	0.164	0.088	0.346	0.368	-0.311
1675	0.179	0.107	-0.144	0.306	0.362	0.292
1676	-0.399	-0.045	-0.082	-0.464	0.191	0.027
1677	0.300	-0.160	0.017	0.170	0.000	0.691
1678	-0.737	-0.165	-0.191	-0.071	0.041	-0.423
1679	0.353	-0.061	-0.015	-0.345	-0.188	-0.287
1680	0.675	0.101	0.203	0.381	0.245	0.094
1681	-0.299	-0.229	0.119	-0.125	0.023	-0.229
1682	-0.106	-0.292	0.216	-0.313	-0.047	-0.109
1683	0.349	0.127	0.286	0.165	0.488	0.309
1684	-0.456	-0.027	-0.290	-0.183	-0.344	0.416
1685	-0.651	-0.083	-0.587	-0.723	-0.520	-0.196
1686	0.071	0.555	0.549	0.205	0.263	0.343
1687	0.587	0.141	0.284	0.168	0.199	-0.017
1688	0.131	0.122	0.457	0.076	-0.066	0.049
1689	0.169	0.116	0.224	0.139	-0.142	-0.056
1690	0.162	0.073	0.112	0.196	0.189	0.812
1691	-0.197	0.031	-0.553	-0.031	-0.172	0.352
1692	0.413	0.091	0.687	0.044	0.473	0.106
1693	0.133	-0.160	0.243	0.367	0.417	0.915
1694	0.176	0.179	-0.046	0.092	0.407	-0.196
1695	0.294	-0.008	-0.081	0.128	0.174	0.130
1696	-0.181	-0.246	-0.372	-0.547	-0.372	-0.638
1697	-0.253	-0.014	-0.123	0.210	0.104	0.239
1698	-0.162	0.037	-0.042	-0.181	0.215	0.648
1699	0.361	0.221	0.409	0.481	0.484	0.456
1700	0.073	0.065	0.079	0.622	-0.008	0.622
1701	0.243	-0.625	0.146	0.209	0.310	0.109
1702	-0.036	-0.291	-0.242	0.031	-0.467	-0.123
1703	0.003	-0.159	0.261	-0.154	0.289	-0.247
1704	0.069	-0.232	0.011	-0.533	-0.226	-0.349
1705	0.199	0.059	-0.524	-0.013	-0.076	0.327
1706	0.028	0.034	-0.117	0.021	0.068	0.250
1707	-0.276	-0.242	-0.372	-0.475	-0.083	-0.771
1708	-0.283	-0.205	0.169	0.084	0.226	-0.293
1709	-0.080	-0.191	-0.417	0.022	-0.320	-0.231
1710	0.199	0.146	0.455	0.389	0.450	0.289

	AFN	BCR	BKM	EPN	MJN	RPP
1711	0.005	-0.397	0.033	-0.143	0.039	0.058
1712	0.205	-0.041	0.295	0.050	0.156	0.167
1713	-0.458	0.089	-0.264	-0.321	-0.398	0.195
1714	-0.322	0.122	0.197	0.213	-0.243	0.533
1715	-0.096	-0.037	-0.327	-0.148	-0.372	-0.098
1716	-0.049	-0.167	-0.412	-0.048	-0.409	-0.410
1717	0.089	0.086	0.063	0.328	0.236	0.206
1718	0.016	0.090	0.137	0.328	0.336	0.035
1719	0.089	-0.293	-0.099	0.038	0.184	-0.132
1720	0.650	0.088	0.339	0.377	0.204	0.094
1721	-0.294	-0.315	0.519	-0.039	0.218	0.139
1722	0.057	0.214	0.171	-0.066	0.160	-0.142
1723	0.121	0.139	-0.099	-0.241	-0.251	0.287
1724	0.001	-0.052	-0.069	-0.352	0.069	-0.393
1725	0.007	0.463	-0.097	0.041	-0.164	-0.125
1726	0.619	0.502	0.504	0.509	0.168	0.558
1727	-0.096	-0.577	-0.130	-0.012	0.042	-0.141
1728	-0.763	-0.320	-0.503	-0.428	0.059	-0.134
1729	-0.619	-0.161	-0.220	-0.262	0.467	-0.021
1730	0.132	0.688	-0.257	0.286	0.018	0.043
1731	0.229	-0.107	-0.376	-0.188	-0.013	-0.473
1732	-0.012	0.217	-0.009	0.070	0.384	-0.071
1733	-0.551	-0.285	-0.667	-0.791	-0.819	-0.609
1734	0.218	-0.067	0.038	-0.127	0.179	0.314
1735	-0.011	-0.209	-0.320	-0.736	-0.103	-0.482
1736	0.127	0.359	0.042	-0.065	-0.189	-0.286
1737	-0.078	0.104	-0.056	-0.099	-0.174	0.064
1738	0.036	0.182	-0.081	0.052	0.201	0.244
1739	-0.752	0.016	-0.308	-0.486	-0.542	-0.184
1740	-0.271	-0.052	-0.029	0.230	0.277	-0.238
1741	0.139	0.305	0.130	0.274	0.430	0.179
1742	0.364	0.143	-0.261	-0.199	-0.141	0.054
1743	0.253	-0.151	0.409	0.349	0.449	0.252
1744	-0.253	-0.060	-0.177	0.214	-0.316	0.271
1745	0.318	-0.013	0.161	0.269	0.082	0.201
1746	0.424	-0.144	0.487	0.563	0.810	0.436
1747	0.245	-0.030	0.831	0.134	0.259	0.386
1748	-1.073	-0.508	-1.070	-0.888	-0.618	-1.214
1749	0.186	0.557	0.268	0.574	0.144	0.368
1750	-0.305	0.330	-0.253	-0.010	-0.451	0.149
1751	0.187	0.211	0.142	-0.004	0.371	0.505
1752	0.305	-0.417	-0.407	-0.694	-0.760	-0.708
1753	0.026	-0.163	-0.343	-0.515	-0.475	-0.371
1754	0.352	0.318	0.105	0.029	-0.232	0.466
1755	0.089	0.029	-0.067	-0.074	-0.574	-0.169
1756	-0.749	-0.406	-0.119	-0.191	-0.122	-0.486
1757	-0.292	0.076	-0.426	-0.395	-0.394	-0.313
1758	0.480	0.429	0.514	-0.219	0.222	0.123
1759	0.536	-0.128	0.431	-0.080	0.293	0.091

	AFN	BCR	BKM	EPN	MJN	RPP
1760	-0.126	-0.112	-0.220	-0.241	-0.167	-0.266
1761	0.063	0.293	-0.142	-0.600	-0.114	-0.489
1762	0.222	-0.108	0.626	0.155	0.650	0.319
1763	-0.304	-0.178	-0.327	-0.628	-0.554	0.072
1764	0.067	0.044	0.321	0.156	0.091	0.330
1765	-0.304	0.183	0.179	-0.371	-0.247	0.058
1766	0.164	0.116	0.334	0.415	-0.261	0.382
1767	0.333	-0.138	0.153	-0.187	-0.107	-0.292
1768	0.379	-0.074	0.208	-0.084	0.027	0.162
1769	-0.638	-0.236	0.063	0.048	0.048	-0.282
1770	0.147	0.168	0.250	0.352	0.354	-0.037
1771	0.628	0.265	0.279	0.670	0.716	0.286
1772	0.072	-0.069	-0.340	-0.186	-0.110	-0.192
1773	-0.955	-0.398	-0.796	-1.008	-0.918	-0.981
1774	-0.247	-0.045	-0.134	-0.336	-0.544	-0.364
1775	0.261	0.248	0.150	0.634	0.319	-0.070
1776	0.034	0.216	-0.103	-0.102	0.104	-0.157
1777	-0.687	-0.129	-0.385	-0.576	-0.552	-0.176
1778	0.071	0.526	-0.025	0.067	0.112	0.340
1779	-0.178	-0.086	0.149	-0.095	0.306	-0.100
1780	-0.135	-0.256	-0.526	-0.392	-0.632	-0.229
1781	-0.112	-0.104	-0.037	-0.106	-0.131	0.067
1782	-0.597	-0.289	-0.399	-0.457	-0.324	-0.444
1783	0.527	0.298	0.287	0.858	0.327	0.442
1784	0.387	0.403	0.481	0.595	0.416	0.956
1785	-0.503	-0.067	-0.371	-0.231	-0.026	-0.014
1786	0.104	0.113	-0.225	-0.105	-0.264	-0.138
1787	0.553	0.132	0.396	0.739	0.410	0.540
1788	-0.482	-0.257	-0.269	-0.610	-0.182	-0.650
1789	-0.225	-0.003	-0.184	0.520	0.190	-0.069
1790	0.790	0.589	-0.199	0.593	0.389	0.334
1791	0.542	0.070	0.316	0.485	0.141	0.192
1792	0.352	-0.080	0.138	0.655	0.173	0.295
1793	0.686	0.026	0.885	0.932	0.653	0.961
1794	-0.060	-0.383	-0.304	-1.069	-0.613	-0.900
1795	0.056	-0.077	0.382	0.459	0.233	0.076
1796	-0.625	-0.092	0.163	0.511	-0.162	0.317
1797	-0.313	0.020	-0.297	-0.201	-0.545	-0.093
1798	0.031	0.060	-0.363	-0.096	0.080	-0.186
1799	-0.532	0.446	0.355	0.490	-0.027	0.899
1800	0.049	0.071	-0.135	0.160	-0.131	0.482
1801	0.354	-0.286	-0.135	0.051	-0.232	-0.373
1802	-0.081	-0.096	0.472	0.423	0.091	0.073
1803	-0.133	0.042	-0.358	-0.528	-0.622	-0.594
1804	0.411	0.103	0.537	0.422	0.297	0.194
1805	-0.512	0.045	-0.152	-0.278	-0.356	-0.001
1806	-0.746	-0.141	-0.327	-0.490	-0.489	-0.587
1807	0.595	-0.060	0.331	0.334	0.327	-0.026
1808	-0.419	0.026	0.292	-0.439	0.171	-0.132

	AFN	BCR	BKM	EPN	MJN	RPP
1809	0.414	0.170	0.116	0.087	-0.044	0.314
1810	0.085	-0.169	0.364	0.345	0.550	0.111
1811	-0.211	-0.011	-0.100	0.300	-0.192	0.139
1812	-0.308	-0.051	0.301	0.007	-0.228	-0.110
1813	-0.241	-0.291	-0.441	-0.065	-0.410	-0.426
1814	0.359	0.004	0.019	-0.023	-0.175	-0.059
1815	0.342	-0.061	0.630	0.338	0.454	0.530
1816	0.755	-0.142	0.615	0.910	0.636	0.639
1817	0.592	-0.470	-0.294	-0.243	-0.221	-0.256
1818	-0.232	-0.552	-0.770	-0.802	-0.897	-1.022
1819	-0.873	-0.386	-0.037	-0.676	-0.421	-0.465
1820	-0.113	0.125	-0.229	-0.548	-0.469	-0.289
1821	-0.336	-0.075	0.144	0.075	0.008	0.251
1822	-0.701	-0.032	-0.502	-0.468	-0.367	-0.536
1823	-0.314	0.024	-0.062	-0.423	0.098	-0.047
1824	-0.363	0.168	0.029	0.281	0.281	0.225
1825	0.034	0.088	-0.011	0.041	-0.192	0.115
1826	-0.232	0.464	-0.252	-0.119	0.112	0.337
1827	0.109	0.194	-0.021	-0.408	0.365	-0.092
1828	0.547	0.159	0.414	0.163	0.663	0.255
1829	-0.334	-0.268	0.193	0.224	0.397	0.029
1830	0.303	0.008	0.491	0.306	0.373	0.573
1831	0.081	-0.080	-0.193	0.169	-0.593	0.065
1832	0.249	0.208	0.048	0.409	-0.340	0.798
1833	0.477	-0.001	0.483	0.225	0.520	0.403
1834	0.218	-0.160	0.426	0.239	0.074	0.111
1835	0.182	-0.053	0.001	0.562	0.071	0.483
1836	0.038	-0.078	-0.571	-0.107	-0.557	0.183
1837	0.431	-0.287	0.175	0.160	0.173	0.022
1838	-0.113	-0.364	0.120	0.113	-0.488	0.131
1839	0.520	0.030	0.556	0.620	0.357	0.883
1840	-0.198	-0.094	0.361	0.082	-0.034	-0.299
1841	-0.450	-0.208	-0.110	-0.854	-0.095	-0.723
1842	-0.392	-0.180	-0.693	-0.249	-0.379	-0.363
1843	0.222	0.330	-0.017	0.168	0.140	0.099
1844	0.593	0.315	0.374	0.339	0.359	0.050
1845	-0.042	0.290	0.280	-0.020	0.408	-0.372
1846	0.273	-0.113	0.252	0.396	0.122	0.276
1847	-0.678	-0.495	-0.533	-0.624	-0.545	-0.957
1848	-0.184	0.217	0.486	0.382	-0.200	0.097
1849	0.443	-0.275	0.663	0.622	0.726	-0.121
1850	0.353	-0.237	0.320	0.240	0.283	0.007
1851	-0.816	-0.181	-0.352	-0.683	-0.777	-0.317
1852	0.517	0.140	0.537	0.140	0.257	0.404
1853	0.036	0.117	-0.187	-0.245	-0.299	-0.190
1854	-0.015	0.208	-0.318	-0.293	-0.191	-0.229
1855	0.659	-0.194	0.045	0.266	0.054	0.141
1856	0.023	0.066	0.300	0.190	0.440	0.070
1857	-1.044	-0.145	0.066	0.071	0.128	0.280

	AFN	BCR	BKM	EPN	MJN	RPP
1858	0.071	0.267	0.414	-0.114	-0.079	0.351
1859	-0.503	-0.357	-0.325	-0.552	-0.758	-0.447
1860	0.352	0.070	0.323	0.204	0.022	0.170
1861	-0.461	-0.358	-0.518	-0.205	-0.595	-0.469
1862	-0.422	-0.110	-0.473	-0.026	-0.750	-0.021
1863	-0.254	-0.001	-0.549	-0.334	-0.511	-0.680
1864	-0.127	-0.244	-0.048	-0.567	-0.330	-0.540
1865	0.148	0.070	0.007	0.423	0.418	0.171
1866	0.119	0.174	0.172	0.377	0.209	0.641
1867	0.515	-0.200	0.174	0.338	0.234	0.181
1868	0.684	0.342	0.480	0.506	0.456	0.694
1869	0.531	0.061	0.395	0.112	0.364	0.000
1870	-0.500	0.264	-0.207	-0.034	-0.116	-0.004
1871	-0.347	-0.682	-0.283	-0.267	0.462	-0.567
1872	-0.873	-0.184	-0.087	-0.246	-0.197	-0.127
1873	-0.011	-0.270	-0.381	-0.338	-0.004	-0.253
1874	0.184	-0.027	0.124	0.563	0.304	-0.140
1875	-0.223	0.318	-0.026	0.400	-0.338	0.360
1876	0.153	-0.048	-0.049	-0.241	0.336	-0.298
1877	0.253	0.321	0.180	0.210	0.547	0.140
1878	0.097	0.494	0.242	-0.642	-0.131	-0.060
1879	-0.207	-0.063	-0.148	-0.417	0.245	-0.416
1880	-0.425	-0.077	-0.607	-0.504	-0.567	-0.090
1881	-0.329	0.323	-0.126	-0.344	-0.158	-0.297
1882	0.285	-0.338	0.598	0.091	0.142	0.201
1883	-0.765	-0.105	-0.210	-0.280	-0.234	-0.130
1884	-0.176	-0.043	-0.003	-0.052	0.173	-0.067
1885	-0.339	0.140	0.288	0.290	0.759	0.356
1886	-0.578	-0.290	-0.270	-0.099	0.072	0.134
1887	0.133	0.066	0.075	-0.354	0.310	-0.269
1888	0.235	-0.073	-0.025	-0.084	-0.122	-0.158
1889	0.337	0.033	0.101	0.307	0.387	0.054
1890	0.010	0.077	-0.357	0.267	-0.521	-0.170
1891	0.210	-0.183	0.354	0.059	0.981	-0.007
1892	0.249	-0.260	-0.265	-0.265	-0.279	-0.234
1893	-0.805	0.075	-0.657	-0.617	-0.682	-0.045
1894	-0.009	-0.630	-0.329	-0.575	-0.364	-0.570
1895	-0.181	0.253	-0.494	0.174	-0.273	0.071
1896	0.122	0.206	-0.001	0.190	-0.210	0.144
1897	0.231	0.079	0.067	0.326	0.411	-0.118
1898	0.407	0.301	0.746	0.308	0.806	0.659
1899	-1.019	0.227	-0.411	-0.228	-0.090	-0.171
1900	-0.468	-0.410	-0.501	-0.764	-0.507	-0.810
1901	-0.354	0.537	0.073	0.377	0.163	0.228
1902	-0.491	-0.051	-0.388	-0.875	-0.337	-0.701
1903	-0.158	0.251	0.671	0.652	1.449	-0.019
1904	-0.583	-0.360	-0.899	-1.025	-0.857	-0.695
1905	0.684	0.422	0.358	0.658	1.085	0.409
1906	0.231	0.072	0.275	0.255	0.987	0.214

	AFN	BCR	BKM	EPN	MJN	RPP
1907	0.700	0.802	0.632	0.656	1.162	0.925
1908	0.734	0.734	0.300	1.002	0.468	1.072
1909	0.050	-0.076	-0.054	-0.001	-0.401	-0.008
1910	-0.132	-0.221	-0.601	-0.710	-0.892	-0.458
1911	0.738	0.369	0.481	0.550	0.660	0.213
1912	0.479	0.135	0.468	0.481	0.914	0.559
1913	-0.381	-0.316	-0.202	-0.329	0.089	-0.360
1914	0.771	0.503	0.554	0.507	1.144	0.608
1915	0.675	-0.081	0.275	0.579	-0.154	0.531
1916	0.476	0.314	0.296	0.133	-0.130	0.512
1917	0.179	0.178	0.639	0.655	0.285	0.304
1918	-0.777	0.172	-0.486	-0.371	-0.850	-0.283
1919	1.029	-0.008	0.687	0.727	0.589	1.440
1920	0.250	-0.112	0.291	0.331	0.004	-0.043
1921	-0.879	0.409	-0.001	-1.044	0.170	-1.067
1922	0.026	-0.289	-0.911	-0.254	-0.157	-0.449
1923	0.166	-0.307	0.009	-0.714	-0.011	-0.284
1924	0.542	0.262	0.345	-0.175	0.326	0.363
1925	-1.289	-0.308	-0.747	-0.628	-1.066	-0.668
1926	0.848	-0.052	0.401	0.560	0.180	0.868
1927	0.024	0.113	0.240	0.211	0.215	0.277
1928	0.048	0.136	0.416	-0.389	0.332	0.102
1929	-0.507	0.106	-0.128	-0.044	0.131	0.009
1930	0.569	-0.013	0.453	0.162	0.057	0.322
1931	0.318	-0.139	0.553	0.664	0.236	0.108
1932	0.630	-0.211	0.309	0.173	-0.314	0.582
1933	0.273	-0.201	0.607	0.241	0.214	0.430
1934	-0.177	-0.223	-0.070	-0.907	-0.598	-0.717
1935	0.610	0.033	-0.294	0.297	0.334	0.582
1936	-0.819	0.088	-0.225	-0.048	-0.328	0.082
1937	-0.038	-0.071	0.455	0.536	0.170	-0.005
1938	-0.104	0.039	-0.118	-0.017	-0.399	0.293
1939	0.188	-0.203	-0.275	-0.301	-0.386	-0.157
1940	-0.016	0.041	0.169	0.547	0.372	0.029
1941	0.789	0.363	0.730	0.526	0.494	0.767
1942	-0.132	0.136	-0.084	-0.117	0.075	-0.269
1943	0.332	-0.013	-0.425	0.168	-0.235	-0.153
1944	-0.495	0.034	-0.064	-0.339	-0.623	-0.139
1945	0.268	0.047	0.086	0.055	0.278	-0.014
1946	-0.476	-0.501	-0.718	-0.521	-0.449	-0.590
1947	0.252	-0.017	-0.124	-0.102	-0.373	-0.385
1948	0.230	-0.202	-0.064	-0.261	-0.072	-0.059
1949	-0.405	0.194	0.313	0.454	0.147	0.134
1950	-0.949	-0.324	-0.508	-0.603	-0.708	-0.587
1951	-0.618	-0.443	-0.404	-0.425	-0.784	-0.261
1952	-0.045	0.377	0.375	0.762	0.540	0.308
1953	-0.263	0.058	0.037	-0.704	-0.097	-0.393
1954	-0.527	0.022	-0.520	-0.046	-0.831	-0.064
1955	-0.522	-0.354	-0.477	-0.289	-0.549	-0.557

	AFN	BCR	BKM	EPN	MJN	RPP
1956	0.199	-0.272	-0.684	-0.600	-0.706	-0.418
1957	-0.352	0.314	-0.073	0.363	-0.241	0.324
1958	0.020	0.048	0.156	0.224	0.467	0.013
1959	-0.627	-0.018	-0.401	-0.498	-0.036	-0.307
1960	0.445	-0.043	0.245	0.271	0.226	0.022
1961	-0.230	-0.227	-0.502	-0.565	-0.426	-0.271
1962	-0.099	0.192	0.429	0.002	0.118	-0.009
1963	0.097	-0.072	0.080	-0.040	0.044	0.240
1964	-0.377	-0.071	-0.582	-0.067	-0.096	-0.286
1965	-0.088	0.080	0.317	0.221	0.409	0.246
1966	-0.283	-0.161	0.106	0.139	0.524	0.057
1967	-0.126	0.068	-0.631	-0.262	-0.429	-0.255
1968	0.076	-0.041	0.414	0.275	0.448	0.407
1969	-0.120	-0.097	-0.049	-0.141	-0.799	-0.512
1970	-0.094	0.103	0.178	0.379	-0.193	0.058
1971	-0.550	-0.675	-0.761	-1.031	-0.801	-0.887
1972	0.228	0.275	0.240	0.412	0.199	0.088
1973	0.257	0.117	0.481	0.342	0.310	0.031
1974	-0.588	-0.257	-0.886	-1.057	-0.835	-0.744
1975	0.478	0.190	0.502	0.409	0.644	0.446
1976	0.056	0.150	0.242	-0.075	0.204	0.110
1977	-0.177	-0.025	0.015	-0.354	0.257	-0.281
1978	0.508	-0.041	-0.034	0.286	-0.243	0.103
1979	0.376	0.330	0.427	0.787	0.805	0.469
1980	-0.052	0.281	-0.306	0.340	-0.103	0.117
1981	-0.302	0.433	-0.368	0.351	-0.596	-0.169
1982	0.095	0.393	0.115	0.174	0.086	0.263
1983	0.467	0.148	0.379	0.447	0.439	0.318
1984	0.203	-0.109	-0.086	-0.183	0.267	-0.194
1985	0.600	0.367	0.546	-0.337	0.440	0.392
1986	-0.094	0.470	0.644	-0.209	0.194	0.094

APPENDIX 4. ESTIMATED REGRESSION EQUATIONS FOR RECONSTRUCTION

Listed below are the estimated regression coefficients for generating streamflow at gages 4485, 4420, and 4445 from tree-ring indices (AR-residual chronologies). The predictand in the model is the log of streamflow (log acre-ft). The equations apply to the "full" calibration period, as described in the text. Site codes AFN, BCR, etc., refer to the tree-ring site names (Table 2 in text). The tree-ring chronologies themselves are included as another appendix. The suffixes "1", "2", and "3" on the predictors indicate whether the tree-ring variable is lagged -1, 0, or +1 years relative to the streamflow series.

	GAGE NUMBER		
PARAMETERS, FULL MODEL	4485	4420	4445
Constant	5.421399	5.023775	5.060159
AFN1	0.079931	0	0
AFN2	0	0	0
AFN3	0.130341	0.115371	0
BCR1	0	0	0
BCR2	0	0	0
BCR3	0.195606	0.179856	0.274796
BKM1	0	0	0
BKM2	0.175618	0.210499	0.163385
BKM3	-0.183713	-0.166062	0
EPN1	0	0	0
EPN2	0.131533	0.120432	0.169266
EPN3	0	0	-0.165311
MJN1	0.130100	0.143238	0.206773
MJN2	0.194161	0.195692	0.226508
MJN3	0	0	0
RPP1	0	0	0
RPP2	0.148643	0.145569	0.100549
RPP3	0	0	0

APPENDIX 5 ANNUAL RECONSTRUCTED FLOWS AND MOVING AVERAGES

Units are acre-ft. First three columns are annual (water-year) totals. Next three columns are 10-yr running means, listed at the ending year of the ten year period. Last three columns are the 70-yr running means. Gages are coded by USGS gage numbers 4485, 4420, and 4445.

	Gage4485	Gage4420	Gage4445	Ten_4485	Ten_4420	Ten_4445	70_4485	70_4420	70_4445
1663	204065	73963	79552	NA	NA	NA	NA	NA	NA
1664	162387	59210	69876	NA	NA	NA	NA	NA	NA
1665	271704	129161	129280	NA	NA	NA	NA	NA	NA
1666	151386	55757	65337	NA	NA	NA	NA	NA	NA
1667	146336	55057	50789	NA	NA	NA	NA	NA	NA
1668	139567	58563	67365	NA	NA	NA	NA	NA	NA
1669	159930	62288	86170	NA	NA	NA	NA	NA	NA
1670	119151	51376	53541	NA	NA	NA	NA	NA	NA
1671	357743	150745	137446	NA	NA	NA	NA	NA	NA
1672	260900	103799	118212	197316.9	79991.91	85756.80	NA	NA	NA
1673	315253	119457	134877	208435.7	84541.30	91289.30	NA	NA	NA
1674	374821	151194	148335	229679.1	93739.70	99135.21	NA	NA	NA
1675	343839	143174	218884	236892.6	95141.00	108095.60	NA	NA	NA
1676	283891	111379	103988	250143.1	100703.20	111960.70	NA	NA	NA
1677	281298	123819	146920	263639.3	107579.40	121573.80	NA	NA	NA
1678	242334	89890	105672	273916.0	110712.09	125404.50	NA	NA	NA
1679	204687	93047	79638	278391.7	113788.00	124751.30	NA	NA	NA
1680	292978	112628	138556	295774.4	119913.20	133252.80	NA	NA	NA
1681	235231	86979	115555	283523.2	113536.59	131063.70	NA	NA	NA
1682	245311	106021	107955	281964.3	113758.80	130038.01	NA	NA	NA
1683	405492	169156	194776	290988.2	118728.70	136027.89	NA	NA	NA
1684	275157	102630	139100	281021.8	113872.30	135104.41	NA	NA	NA
1685	106873	44711	56477	257325.2	104026.00	118863.71	NA	NA	NA
1686	379363	172529	152079	266872.4	110141.00	123672.80	NA	NA	NA
1687	336013	137751	179352	272343.9	111534.20	126916.01	NA	NA	NA
1688	382382	142893	154068	286348.7	116834.50	131755.61	NA	NA	NA
1689	288289	113630	113894	294708.9	118892.80	135181.20	NA	NA	NA
1690	502640	190758	166101	315675.1	126705.80	137935.70	NA	NA	NA
1691	209937	79108	104185	313145.7	125918.70	136798.70	NA	NA	NA
1692	361995	159682	143697	324814.1	131284.80	140372.89	NA	NA	NA
1693	776736	289610	302149	361938.5	143330.20	151110.20	NA	NA	NA
1694	390688	152037	159795	373491.6	148270.91	153179.70	NA	NA	NA
1695	347350	134915	169066	397539.3	157291.30	164438.59	NA	NA	NA
1696	141279	53403	56990	373730.9	145378.70	154929.70	NA	NA	NA
1697	259485	104706	122002	366078.1	142074.20	149194.70	NA	NA	NA
1698	344138	143851	137795	362253.7	142170.00	147567.41	NA	NA	NA
1699	550792	232638	210560	388504.0	154070.81	157234.02	NA	NA	NA
1700	382305	146217	135788	376470.5	149616.70	154202.70	NA	NA	NA
1701	345590	137645	129964	390035.8	155470.39	156780.61	NA	NA	NA
1702	179935	69197	89864	371829.8	146421.91	151397.31	NA	NA	NA
1703	231385	95123	110957	317294.7	126973.20	132278.09	NA	NA	NA
1704	268565	106869	91955	305082.4	122456.40	125494.10	NA	NA	NA
1705	234111	87305	88542	293758.5	117695.40	117441.70	NA	NA	NA
1706	278629	106389	120627	307493.5	122994.00	123805.41	NA	NA	NA
1707	116392	46983	58411	293184.2	117221.70	117446.31	NA	NA	NA
1708	287353	121567	112314	287505.7	114993.30	114898.20	NA	NA	NA
1709	170719	70539	83673	249498.4	98783.40	102209.49	NA	NA	NA
1710	356212	149413	151255	246889.1	99102.99	103756.20	NA	NA	NA
1711	290760	115165	134749	241406.1	96855.00	104234.70	NA	NA	NA

	Gage4485	Gage4420	Gage4445	Ten_4485	Ten_4420	Ten_4445	70__4485	70_4420	70_4445
1712	352032	144320	179694	258615.8	104367.30	113217.70	NA	NA	NA
1713	184887	71527	83699	253966.0	102007.70	110491.90	NA	NA	NA
1714	293761	126036	114539	256485.6	103924.41	112750.30	NA	NA	NA
1715	172582	70465	63003	250332.7	102240.41	110196.39	NA	NA	NA
1716	145597	56694	55379	237029.5	97270.90	103671.59	NA	NA	NA
1717	308633	122859	121921	256253.6	104858.50	110022.59	NA	NA	NA
1718	370967	148176	151248	264615.0	107519.40	113915.99	NA	NA	NA
1719	323418	127925	128871	279884.9	113258.00	118435.80	NA	NA	NA
1720	262949	110596	155938	270558.6	109376.30	118904.09	NA	NA	NA
1721	464273	172628	205877	287909.9	115122.59	126016.90	NA	NA	NA
1722	330154	140957	166726	285722.1	114786.30	124720.10	NA	NA	NA
1723	247883	98109	112766	292021.7	117444.50	127626.81	NA	NA	NA
1724	253675	97138	108136	288013.1	114554.70	126986.51	NA	NA	NA
1725	284888	111146	117383	299243.7	118622.80	132424.52	NA	NA	NA
1726	371664	154353	135624	321850.4	128388.70	140449.00	NA	NA	NA
1727	243155	88038	112145	315302.6	124906.59	139471.41	NA	NA	NA
1728	156437	63178	81879	293849.6	116406.79	132534.50	NA	NA	NA
1729	381538	167626	172788	299661.6	120376.89	136926.20	NA	NA	NA
1730	325870	141387	149011	305953.7	123456.00	136233.50	NA	NA	NA
1731	205700	78038	92935	280096.4	113997.00	124939.30	NA	NA	NA
1732	319605	122799	158538	279041.5	112181.20	124120.49	285614.9	114684.6	124231.9
1733	101860	39901	44929	264439.2	106360.40	117336.80	284154.8	114198.0	123737.3
1734	228389	98670	102773	261910.6	106513.60	116800.49	285097.7	114761.7	124207.2
1735	197934	75049	90763	253215.2	102903.90	114138.49	284043.8	113988.6	123657.0
1736	222434	89212	101882	238292.2	96389.80	110764.30	285058.8	114466.6	124179.1
1737	260020	99677	100835	239978.7	97553.71	109633.30	286682.9	115104.0	124894.0
1738	264322	107197	149468	250767.2	101955.61	116392.20	288465.1	115798.8	126066.9
1739	144431	57617	59642	227056.5	90954.70	105077.60	288243.7	115732.1	125687.9
1740	244476	108793	114712	218917.1	87695.30	101647.70	290034.1	116552.3	126561.8
1741	534696	221348	235854	251816.7	102026.29	115939.60	292562.0	117560.9	127967.6
1742	211540	83338	88521	241010.2	98080.19	108937.90	291856.8	117268.6	127543.5
1743	459540	176062	170639	276778.2	111696.30	121508.90	293918.1	118077.3	128054.4
1744	305742	115299	116932	284513.5	113359.20	122924.80	292931.2	117564.5	127605.8
1745	255358	107709	93929	290255.9	116625.20	123241.40	291667.2	117057.8	125820.7
1746	515873	205441	281122	319599.8	128248.10	141165.41	294981.3	118401.6	128351.2
1747	615528	251339	309583	355150.6	143414.30	162040.20	299756.0	120223.3	130674.9
1748	89843	32223	38433	337702.7	135916.91	150936.70	297577.5	119399.5	129714.4
1749	340198	161705	171899	357279.4	146325.70	162162.41	299513.4	120380.3	131032.4
1750	241766	91058	104322	357008.4	144552.20	161123.41	298781.8	120072.2	130543.3
1751	348990	145370	133161	338437.8	136954.39	150854.08	300406.9	120906.3	130794.9
1752	126932	48587	56223	329977.0	133479.30	147624.30	298715.8	120085.9	130055.8
1753	144659	51772	49830	298488.9	121050.30	135543.41	294989.6	118408.9	127985.2
1754	273992	107245	99658	295313.9	120244.91	133816.00	294972.9	118474.9	127421.7
1755	127674	49083	57772	282545.5	114382.30	130200.30	295270.1	118537.3	127440.2
1756	184907	70730	79320	249448.9	100911.21	110020.09	292492.2	117083.1	126400.8
1757	140577	62169	85476	201953.8	81994.20	87609.41	289700.2	116003.3	125059.7
1758	272454	119606	116494	220214.9	90732.50	95415.50	288129.8	115670.6	124522.9
1759	422979	161846	176815	228493.0	90746.60	95907.10	290053.9	116359.4	125421.8
1760	282926	100590	144256	232609.0	91699.80	99900.50	286915.2	115071.3	125109.8

	Gage4485	Gage4420	Gage4445	Ten_4485	Ten_4420	Ten_4445	70__4485	70_4420	70_4445
1761	121263	50868	58963	209836.3	82249.60	92480.7	285648.4	114667.9	124463.7
1762	502553	208323	250789	247398.4	98223.20	111937.3	287656.4	115362.8	125993.6
1763	175867	68678	79964	250519.2	99913.80	114950.7	279072.6	112206.6	122819.5
1764	270349	116075	154835	250154.9	100796.80	120468.4	277353.5	111692.9	122748.7
1765	231526	94240	90903	260540.1	105312.50	123781.5	275698.8	111111.8	121632.1
1766	296904	126300	127698	271739.8	110869.50	128619.3	277922.0	112153.2	122642.2
1767	216450	84821	86994	279327.1	113134.70	128771.1	277307.3	111869.1	122142.1
1768	222845	87997	101723	274366.2	109973.81	127294.0	275574.5	111071.2	121626.8
1769	279305	104879	113411	259998.8	104277.11	120953.6	271696.1	109246.1	120238.9
1770	409750	183375	161822	272681.2	112555.61	122710.2	272088.2	109776.9	120610.8
1771	718142	280547	312660	332369.1	135523.50	148079.9	277410.3	111818.4	123220.8
1772	236910	85765	136213	305804.8	123267.70	136622.3	278224.3	112055.0	123882.9
1773	63100	24115	29740	294528.1	118811.41	131599.9	275820.2	111040.6	122722.6
1774	113018	51758	39364	278795.0	112379.70	120052.8	273598.1	110253.3	121971.3
1775	361205	146519	166315	291762.9	117607.59	127594.0	275413.7	111099.2	123082.4
1776	254136	98735	144400	287486.1	114851.10	129264.2	275063.8	110989.9	123422.0
1777	189526	72705	81658	284793.7	113639.50	128730.6	276108.6	111357.3	123754.1
1778	201364	90819	101136	282645.6	113921.70	128671.9	274880.2	110918.1	123594.4
1779	337931	135144	139731	288508.2	116948.20	131303.9	277268.9	111841.0	124395.2
1780	131266	53355	62216	260659.8	103946.20	121343.3	274055.4	110468.8	123123.3
1781	170383	69537	75629	205883.9	82845.20	97640.2	272335.8	109816.9	122278.7
1782	162394	63780	51588	198432.3	80646.70	89177.7	269626.6	108666.4	120448.6
1783	462255	202627	207100	238347.8	98497.91	106913.7	273589.0	110539.2	122211.5
1784	760613	285509	329005	303107.3	121873.00	135877.8	280258.4	112817.4	125275.3
1785	302539	109650	122341	297240.7	118186.10	131480.4	282114.9	113377.2	126122.9
1786	189611	81297	69292	290788.2	116442.30	123969.6	282743.7	113728.7	126321.7
1787	455313	181969	235907	317366.9	127368.70	139394.5	284839.1	114573.1	127950.1
1788	183400	67025	63733	315570.5	124989.30	135654.2	282159.6	113413.8	126699.8
1789	474954	190047	151498	329272.8	130479.61	136830.9	284324.4	114301.2	127023.1
1790	419415	169008	169068	358087.7	142044.91	147516.1	286559.6	115135.7	127210.7
1791	519084	183345	156783	392957.8	153425.70	155631.5	287342.7	115288.8	126509.3
1792	400690	146405	139525	416787.4	161688.20	164425.2	288350.3	115366.6	126120.7
1793	983551	388547	517953	468917.0	180280.20	195510.5	298859.8	119515.7	131909.1
1794	108755	40066	43470	403731.2	155735.89	166957.0	296789.6	118700.4	130985.3
1795	246288	102943	105725	398106.1	155065.19	165295.4	296238.1	118583.2	130818.8
1796	384921	152845	180039	417637.1	162220.00	176370.1	296427.5	118561.7	131453.3
1797	171630	73842	69771	389268.8	151407.31	159756.5	295405.7	118358.9	130847.9
1798	154762	64003	81825	386405.0	151105.11	161565.7	295381.8	118370.7	130847.2
1799	542680	216470	197234	393177.6	153747.41	166139.3	297683.8	119068.5	131196.4
1800	271587	116710	98033	378394.8	148517.61	159035.8	296908.3	118715.9	130468.1
1801	149532	59985	68122	341439.6	136181.61	150169.7	296105.8	118458.0	130113.6
1802	439755	166317	193947	345346.1	138172.80	155611.9	297822.3	119079.7	130619.5
1803	114933	46392	48870	258484.3	103957.31	108703.6	298009.1	119172.5	130675.8
1804	343680	144267	172114	281976.8	114377.41	121568.0	299656.1	119823.8	131666.4
1805	197524	74801	102612	277100.4	111563.21	121256.7	299650.2	119820.3	131835.7
1806	108415	46418	40616	249449.8	100920.51	107314.4	298021.4	119209.0	130960.4
1807	227336	107568	166277	255020.4	104293.10	116965.0	297554.5	119321.7	131895.3
1808	384169	142080	144201	277961.1	112100.80	123202.6	299266.6	119820.0	131820.0
1809	246179	109453	111514	248311.0	101399.09	114630.6	300720.1	120560.5	132561.1

	Gage4485	Gage4420	Gage4445	Ten_4485	Ten_4420	Ten_4445	70__4485	70_4420	70_4445
1810	467816	177712	178671	267933.9	107499.30	122694.4	303910.7	121545.1	133474.8
1811	250963	101299	145761	278077.0	111630.70	130458.3	299857.4	119830.1	132187.7
1812	231953	98387	86876	257296.8	104837.70	119751.2	300149.0	120045.1	132164.2
1813	152152	61263	62974	261018.7	106324.80	121161.6	295757.8	118405.1	130626.2
1814	167210	70357	71843	243371.7	98933.80	111134.5	293778.8	117763.1	129982.0
1815	509333	198364	141511	274552.6	111290.10	115024.4	297407.0	119058.2	130661.8
1816	984484	378376	337190	362159.5	144485.89	144681.8	304101.4	121528.7	131462.8
1817	253034	88111	101764	364729.3	142540.19	138230.5	298922.9	119196.8	128493.9
1818	49055	17585	28356	331217.9	130090.70	126646.0	298340.2	118987.7	128350.0
1819	123502	50523	54581	318950.2	124197.70	120952.7	295244.5	117399.4	126674.0
1820	92387	43577	47275	281407.3	110784.20	107813.1	293110.5	116721.1	125859.0
1821	263004	107344	124459	282611.4	111388.70	105682.9	291882.2	116177.9	125734.7
1822	117515	49139	69195	271167.6	106463.90	103914.8	291747.6	116185.8	125920.0
1823	175128	79996	83125	273465.2	108337.20	105929.9	292182.9	116589.0	126395.7
1824	365404	153843	172346	293284.6	116685.80	115980.2	293488.8	117254.7	127434.1
1825	330397	139428	173243	275391.0	110792.20	119153.4	296384.8	118545.3	129083.7
1826	293144	112415	137770	206257.0	84196.10	99211.4	297931.1	119140.8	129918.7
1827	277720	116749	126182	208725.6	87059.91	101653.2	299890.3	119920.5	130500.2
1828	404542	170182	197698	244274.3	102319.61	118587.4	301777.3	120643.0	131660.2
1829	443591	167154	204716	276283.2	113982.70	133600.9	302071.7	120718.9	132058.8
1830	576487	253664	232512	324693.2	134991.41	152124.6	306265.4	122905.6	133319.6
1831	276266	101979	99111	326019.4	134454.91	149589.8	308479.8	123635.8	133893.2
1832	274661	105310	95581	341734.0	140072.00	152228.4	305224.1	122164.2	131675.9
1833	390129	154845	151944	363234.1	147556.91	159110.3	308285.0	123395.1	132704.2
1834	475846	181407	157831	374278.3	150313.30	157658.8	311220.7	124328.4	132747.0
1835	504341	186917	170472	391672.7	155062.20	157381.7	315118.1	125652.4	133883.7
1836	165110	61312	56280	378869.3	149951.91	149232.7	313235.3	124724.0	132863.5
1837	215097	86841	83821	372607.0	146961.09	144996.6	313215.9	124752.8	132818.1
1838	257346	96395	87710	357887.4	139582.42	133997.8	313708.8	124872.8	132617.9
1839	415073	175502	192887	355035.6	140417.20	132814.9	315648.4	125881.7	133753.3
1840	284064	109531	179098	325793.3	126003.91	127473.5	313852.8	124826.8	134000.1
1841	152967	64054	61389	313463.4	122211.41	123701.3	305778.9	121734.0	130410.5
1842	154056	62385	66943	301402.9	117918.90	120837.5	304595.3	121400.0	129421.0
1843	296461	123286	120126	292036.1	114763.01	117655.7	307929.1	122816.8	130712.2
1844	441140	174473	238196	288565.5	114069.59	125692.2	312616.5	124569.8	133552.6
1845	357399	133889	136537	273871.3	108766.80	122298.7	312562.1	124389.4	133127.3
1846	350672	147321	188469	292427.5	117367.70	135517.6	313941.2	125083.5	133756.8
1847	92156	35078	46718	280133.4	112191.40	131807.3	312550.2	124546.0	133257.7
1848	194819	91317	75438	273880.7	111683.60	130580.1	312456.7	124553.1	132890.6
1849	439297	190115	190497	276303.1	113144.91	130341.1	313904.8	125338.4	133615.8
1850	414876	162999	269872	289384.3	118491.70	139418.5	317956.3	126904.7	136582.3
1851	135804	50747	56626	287668.0	117161.00	138942.2	317462.3	126636.3	136310.8
1852	346492	161336	152201	306911.6	127056.11	147468.0	320092.3	128029.9	137748.1
1853	276661	98636	114826	304931.6	124591.11	146938.0	317441.0	126544.4	136430.0
1854	181780	69450	54102	278995.6	114088.80	128528.6	309171.9	123457.8	132502.8
1855	269450	108074	121949	270200.7	111507.30	127069.8	308699.2	123435.3	132497.2
1856	300641	113854	161295	265197.6	108160.59	124352.4	310285.3	123900.4	133811.5
1857	357526	145383	210525	291734.6	119191.09	140733.1	308888.4	123377.7	133448.9
1858	236300	121030	139804	295882.7	122162.39	147169.7	309644.1	124149.2	134535.6

	Gage4485	Gage4420	Gage4445	Ten_4485	Ten_4420	Ten_4445	70__4485	70_4420	70_4445
1859	118503	46103	46362	263803.3	107761.20	132756.20	304552.0	122092.9	133033.7
1860	229470	101218	88780	245262.7	101583.09	114647.00	301838.5	121124.4	131886.7
1861	144411	52308	54641	246123.4	101739.19	114448.51	296486.0	119252.5	130427.5
1862	137869	55938	54751	225261.1	91199.39	104703.51	292731.4	117960.1	129216.5
1863	78341	32434	39940	205429.1	84579.20	97214.91	279799.9	112872.8	122387.7
1864	137709	57215	46876	201022.0	83355.70	96492.30	280213.5	113117.8	122436.4
1865	354574	141930	145222	209534.4	86741.30	98819.60	281760.5	113674.7	123000.6
1866	500384	196796	173565	229508.7	95035.51	100046.60	283410.0	114302.6	122908.1
1867	471328	183611	186445	240888.9	98858.30	97638.60	287691.3	115870.7	124574.9
1868	698443	260717	277929	287103.2	112827.01	111451.10	295458.2	118680.9	127376.4
1869	518407	191043	250356	327093.6	127321.00	131850.50	295111.4	118317.7	128135.3
1870	209226	77493	84314	325069.2	124948.50	131403.91	294220.6	117757.4	127939.3
1871	142281	63671	96046	324856.2	126084.80	135544.41	294117.0	117810.1	128338.2
1872	231608	99635	105712	334230.1	130454.50	140640.50	291143.5	116857.5	127077.7
1873	148648	68049	59310	341260.8	134016.00	142577.50	291625.1	117166.9	127226.8
1874	390802	155597	178209	366570.1	143854.20	155710.81	292298.3	117328.8	127313.9
1875	339738	129848	148855	365086.5	142646.00	156074.11	294329.9	118115.1	127974.5
1876	252892	103616	109928	340337.3	133328.00	149710.41	296393.8	118932.3	128964.7
1877	535063	210068	375358	346710.8	135973.70	168601.70	300789.9	120396.5	131951.6
1878	265689	107336	131841	303435.4	120635.60	153992.89	299097.4	119900.2	131775.0
1879	228066	88908	103307	274401.3	110422.09	139288.00	298838.6	119606.7	131657.8
1880	152691	61291	85996	268747.8	108801.90	139456.20	294336.8	117943.5	130333.8
1881	107804	47124	49038	265300.1	107147.20	134755.41	292291.7	117169.6	128952.1
1882	293301	132666	162332	271469.4	110450.30	140417.41	293168.1	117659.3	130030.0
1883	196511	74805	86800	276255.7	111125.90	143166.41	293801.8	117852.8	130370.4
1884	188957	88249	106038	256071.2	104391.10	135949.31	294112.5	118108.4	130858.9
1885	432898	186402	217001	265387.2	110046.50	142763.91	293020.6	117937.5	131937.3
1886	304071	129447	183091	270505.1	112629.61	150080.19	283300.3	114381.4	129735.9
1887	246788	111400	115978	241677.6	102762.80	124142.20	283211.1	114714.1	129939.0
1888	276422	108136	104895	242750.9	102842.80	121447.60	286459.2	116007.6	131032.4
1889	444167	166883	149111	264361.0	110640.30	126028.00	291040.1	117669.9	132382.8
1890	186734	69509	85487	267765.3	111462.09	125977.10	292387.9	118040.4	132928.7
1891	440614	176887	163725	301046.3	124438.41	137445.81	294925.3	119033.9	133489.6
1892	266630	104148	162455	298379.2	121586.59	137458.11	297055.5	119819.7	134821.9
1893	101250	37280	35778	288853.1	117834.10	132355.91	296000.1	119209.5	134145.5
1894	124786	54958	46672	282436.0	114505.00	126419.30	292562.7	117796.8	132350.2
1895	210563	78851	80193	260202.5	103749.90	112738.50	290850.8	116931.4	131020.9
1896	257107	103978	93419	255506.1	101202.99	103771.30	290336.0	116810.9	130387.3
1897	313049	122327	156997	262132.2	102295.70	107873.20	290840.7	116890.6	130827.5
1898	806117	332617	465649	315101.7	124743.80	143948.61	296577.5	119211.1	134655.4
1899	231512	86738	125062	293836.2	116729.30	141543.70	293547.8	118062.3	133517.5
1900	92558	43642	52400	284418.6	114142.61	138235.00	286634.4	115062.0	130944.5
1901	277514	119021	166550	268108.6	108356.00	138517.50	286652.3	115305.4	131907.9
1902	92615	40510	49743	250707.1	101992.20	127246.30	284051.6	114379.7	131253.0
1903	690517	311417	404843	309633.8	129405.91	164152.80	288342.9	116616.5	134865.9
1904	138296	55607	60615	310984.8	129470.81	165547.11	283520.8	114819.3	133477.1
1905	476271	209614	207654	337555.6	142547.11	178293.20	283119.8	115143.6	134008.3
1906	1133759	409391	536568	425220.8	173088.41	222608.11	296957.6	120116.1	140869.5
1907	2054892	805588	742695	599405.1	241414.50	281177.91	323240.4	130383.9	150282.0

	Gage4485	Gage4420	Gage4445	Ten_4485	Ten_4420	Ten_4445	70__4485	70_4420	70_4445
1908	1160894	419509	515376	634882.8	250103.70	286150.59	336148.2	134999.8	156391.5
1909	317885	110793	129701	643520.1	252509.20	286614.50	334759.8	134075.4	155488.9
1910	103044	38435	33209	644568.6	251988.50	284695.41	332173.8	133059.8	153404.7
1911	411419	168067	149933	657959.1	256893.11	283033.72	335865.9	134545.7	154669.7
1912	790504	293591	384855	727748.0	282201.22	316544.91	344958.1	137848.6	159211.3
1913	363683	133347	158062	695064.7	264394.19	291866.78	345918.4	137992.3	159753.2
1914	795452	350119	286537	760780.3	293845.41	314458.97	350980.0	140501.6	160443.8
1915	748902	265861	333006	788043.4	299470.09	326994.19	356572.9	142386.9	163250.5
1916	328409	119038	115308	707508.4	270434.81	284868.22	356254.8	141982.9	162205.3
1917	579541	219063	283314	559973.3	211782.30	238930.09	363217.5	144611.2	165585.3
1918	137366	51674	43005	457620.5	174998.80	191693.02	362396.7	144044.9	165122.0
1919	563126	262692	205311	482144.6	190188.70	199254.00	364165.7	145081.7	165333.6
1920	431441	150003	369045	514984.3	201345.50	232837.59	364402.3	144896.1	166750.3
1921	196351	75623	59966	493477.5	192101.11	223840.89	365267.3	145251.4	166798.0
1922	110298	49218	71851	425456.9	167663.78	192540.48	361893.1	143649.7	165650.2
1923	211290	84345	95102	410217.6	162763.59	186244.50	360959.2	143445.6	165368.4
1924	314078	128921	163738	362080.2	140643.80	173964.59	362849.2	144295.2	166934.6
1925	103220	35780	30460	297512.0	117635.70	143710.02	360474.5	143262.4	165627.6
1926	294357	147147	133127	294106.8	120446.60	145491.91	360384.7	143738.0	165225.2
1927	418652	147503	224148	278017.9	113290.60	139575.31	361257.9	143768.3	165419.8
1928	339601	143528	169277	298241.4	122476.00	152202.52	362733.7	144089.7	165840.9
1929	285321	113270	126087	270460.9	107533.80	144280.11	365116.8	145049.2	166979.8
1930	295377	136549	121900	256854.5	106188.40	119565.60	366058.3	145553.9	167453.0
1931	506641	187775	178823	287883.5	117403.60	131451.31	371233.0	147489.2	169227.0
1932	291634	115154	120517	306017.1	123997.20	136317.91	373429.6	148335.1	170166.5
1933	417677	155297	206808	326655.8	131092.41	147488.50	378277.3	150090.3	172550.3
1934	180616	68265	49190	313309.6	125026.80	136033.70	378890.2	150248.2	172583.4
1935	263054	104902	127361	329293.0	131939.00	145723.80	377582.8	149719.2	172328.2
1936	205995	74733	81314	320456.8	124697.60	140542.50	373377.3	147975.4	171010.4
1937	324852	152852	161784	311076.8	125232.51	134306.11	371284.8	147536.0	170658.1
1938	262373	103910	101441	303354.0	121270.70	127522.50	365055.2	145295.9	168136.8
1939	141219	56436	50050	288943.8	115587.30	119918.80	359666.8	143373.0	165275.3
1940	401890	152070	158679	299595.1	117139.41	123596.70	362419.1	144438.3	166337.6
1941	795534	335409	390044	328484.4	131902.81	144718.80	371751.3	148320.3	170537.6
1942	409240	139580	122285	340245.0	134345.41	144895.59	374288.9	148890.9	170774.4
1943	179302	71889	107507	316407.5	126004.60	134965.50	374726.8	148945.8	171462.9
1944	177107	65880	62010	316056.6	125766.10	136247.50	371674.1	147664.1	169802.9
1945	222269	96791	92197	311978.1	124955.00	132731.11	369995.9	147191.9	168993.5
1946	145141	52792	57984	305892.7	122760.91	130398.10	368456.6	146465.8	168251.5
1947	145318	62068	62263	287939.3	113682.50	120446.00	362888.8	144351.6	163778.7
1948	178794	69017	76633	279581.4	110193.20	117965.20	361647.4	143804.2	162990.0
1949	316094	125573	170089	297068.9	117106.91	129969.10	362905.0	144328.0	163944.0
1950	83545	36090	43114	265234.4	105508.90	118412.59	361917.2	143967.9	163331.4
1951	86010	39361	35451	194282.0	75904.10	82953.30	361605.8	143857.0	163137.3
1952	360566	160930	236537	189414.6	78039.10	94378.51	362566.8	144260.8	164197.4
1953	226907	94939	102532	194175.1	80344.10	93881.00	363001.0	144548.4	164422.1
1954	117455	47672	50488	188209.9	78523.30	92728.80	361979.6	143968.8	163628.6
1955	114389	46627	40324	177421.9	73506.91	87541.50	357429.5	141972.0	161104.6
1956	86886	36131	36113	171596.4	71840.80	85354.39	354326.8	140638.9	159004.9

	Gage4485	Gage4420	Gage4445	Ten_4485	Ten_4420	Ten_4445	70__4485	70_4420	70_4445
1957	231785	86305	82764	180243.1	74264.50	87404.49	354112.5	140280.4	158530.4
1958	316081	135946	181215	193971.8	80957.41	97862.70	354679.1	140677.6	159620.7
1959	199428	78971	81521	182305.2	76297.20	89005.91	351182.8	139421.7	158655.1
1960	323790	146642	167125	206329.7	87352.41	101407.00	353140.8	140523.6	159821.4
1961	140197	51462	72098	211748.4	88562.51	105071.70	348849.1	138731.9	158512.4
1962	268306	114826	113541	202522.4	83952.11	92772.10	348873.0	138884.4	157813.7
1963	335535	136971	130774	213385.2	88155.30	95596.30	352219.9	140308.6	159170.8
1964	161676	61755	79027	217807.3	89563.60	98450.20	352746.9	140405.7	159633.0
1965	310199	138040	151240	237388.3	98704.90	109541.80	354170.3	141251.3	160647.9
1966	533935	216138	235502	282093.2	116705.59	129480.70	358125.0	142853.5	162677.7
1967	133753	55722	69427	272290.0	113647.30	128147.02	355563.6	141902.0	161426.7
1968	385710	160825	167763	279252.9	116135.20	126801.80	349557.8	139447.9	157171.2
1969	159427	64251	71468	275252.8	114663.20	125796.50	348528.0	139126.6	156405.6
1970	197788	80284	86148	262652.6	108027.41	117698.80	350031.3	139650.1	156887.7
1971	74399	28961	28724	256072.8	105777.30	113361.39	347129.7	138363.5	154918.7
1972	245077	107584	107900	253749.9	105053.10	112797.29	349307.7	139321.7	155749.5
1973	496165	196320	260153	269812.9	110988.00	125735.19	346531.2	137677.5	153682.5
1974	83594	30806	33208	262004.7	107893.10	121153.29	345749.8	137323.2	153291.0
1975	390157	175106	191905	270000.5	111599.70	125219.80	344519.5	136830.2	153066.0
1976	399272	153622	213345	256534.2	105348.11	123004.09	334026.8	133176.4	148448.6
1977	302731	120168	103821	273432.0	111792.70	126443.50	308996.0	123384.6	139321.8
1978	298935	122219	118046	264754.5	107932.10	121471.80	296682.3	119137.6	133645.7
1979	869585	312457	290669	335770.3	132752.70	143391.91	304563.8	122018.6	135945.2
1980	454464	164679	192115	361437.9	141192.20	153988.61	309584.0	123822.0	138215.3
1981	205433	78549	92339	374541.3	146151.02	160350.11	306641.3	122543.2	137392.5
1982	274654	113826	99509	377499.0	146775.19	159511.02	299272.1	119975.1	133316.1
1983	523574	208931	222452	380239.9	148036.30	155740.91	301556.3	121054.9	134236.0
1984	354288	130342	201111	407309.3	157989.91	172531.19	295253.9	117915.2	133015.6
1985	425592	176310	282043	410852.8	158110.30	181544.98	290635.2	116635.9	132287.6

APPENDIX 6: ESTIMATION OF MISSING MONTHLY STREAMFLOW DATA

Missing monthly streamflow data were estimated using the U.S. Army Corps of Engineers' HEC-4 monthly streamflow simulation computer program. Details of the method can be found in the following reference:

> HEC-4 Monthly Streamflow Simulation, Users Manual,
> Hydrologic Engineering Center, Corps of Engineers,
> Dept. of the Army, Davis, CA, 95616-4687
> (1971)

The software used was the July 17, 1986, version of a microcomputer implementation of HEC-4 by Haestad Methods, Inc. (37 Brookside Road, Waterbury, Connecticut 067708).

Flow records for gages 4485, 4445, 4420 and 4440 were analyzed as a set. HEC-4 fills in missing monthly data at a set of stations so that the "reconstituted" record covers all years from the beginning year of the earliest series to the ending year of the latest series. For the Gila River data set, this period is 1911-1990. Main HEC-4 steps are listed below:

1. Convert observed data to logarithms.

2. Compute means, standard deviations and skews of monthly series.

3. Identify periods of missing data at each gage.

4. From considerations of station overlap and intercorrelation, select "best" predictor stations for adjusting statistics of monthly flow series.

5. Adjust statistics -- mean, standard deviation and skew.

6. Convert each flow series to normally distributed standard deviates, using an approximation of the Pearson Type III distribution.

7. Systematically manipulate correlation matrices between transformed flow records until arriving at "mutually consistent" correlation matrices. For a given station-month (e.g., January flow at gage 4485, the method attempts to build correlation matrices consistent with (1) correlation with the contemporaneous flow series at the other gages, (2) correlation with the previous month's flow at the key gage, and with the previous month's flow at the other gage.

"Consistency" refers to acceptable range of a correlation coefficient between variable i and variable j given the correlations of variables i and j with other variables. For example, a correlation coefficient of 0.01 between January flows at gage 1 and gage 2 is inconsistent with both gages having a correlation of 0.9 with gage 3.

8. Build linear regression equations from the correlation matrices developed in (7).

9. Estimate the missing data. Begin by estimating any missing values for the first month (e.g., October of water-year 1911) at all stations. Proceed sequentially to the second month, third month, etc. Revise the regression equations and correlation matrices as missing data are filled in. For example, once data has been estimated for the second month of record, update estimates for the first month. Introduce a noise component related to the size of the coefficient of multiple determination into each estimated value.

10. When all missing data have been estimated, un-transform the data from the standard deviates back to the original flow units.

The HEC-4 has no built-in verification procedure for checking on accuracy of estimates. A crude check was made by (1) deleting a decade of data from a station, (2) running HEC-4, and (3) examining the estimated and actual data for major discrepancies. We repeated this procedure several times, deleting different time periods, and trying sets of both 3 and 4 stations in the data set. The estimates appeared to track the actual data reasonably well. Because including a fourth station (gage 4440) made an appreciable improvement in estimating very high flows, our final estimation was done using the set 4485, 4445, 4420, and 4440.